

**QUANTITATIVE ASSESSMENT
OF DRIVER SPEEDING BEHAVIOR
USING INSTRUMENTED VEHICLES**

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The Academic Faculty

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**QUANTITATIVE ASSESSMENT OF
DRIVER SPEEDING BEHAVIOR
USING INSTRUMENTED VEHICLES**

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April 18, 2005

IN MEMORY OF

My Father
Harry Edsil Harper
November 17, 1929 – May 30, 1990
"Can't Never Could"

My Grandfather
Master Sergeant James Mullens
June 5, 1921 - July 16, 2004

To Terry, Sam, and Emma...I love you!

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LIST OF ABBREVIATIONS

ABS	Anti-lock Braking System
AIS	Abbreviated Injury Scale
AJC	Atlanta Journal Constitution
CATI	Computer Aided Telephone Interview
CODES	Crash Outcome Data Evaluation System
CPU	Central Processing Unit
DLC	Drivers License Compact
DMI	Distance Measurement Instrument
DMVS	Department of Motor Vehicle Safety
DOAS	Department of Administrative Services
DOT	Department of Transportation
DPS	Department of Public Safety
DUI	Driving Under the Influence
FARS	Fatal Analysis Reporting System
FHWA	Federal Highway Administration
GAO	Government Accounting Office
GBI	Georgia Bureau of Investigation
GCIC	Georgia Crime Information Center
GDOT	Georgia Department of Transportation
GIS	Geographic Information System
GO	Georgia On-line
GPS	Global Positioning System
GSP	Georgia State Patrol

GT	Georgia Institute of Technology
HH	Household
HZ	Hertz
ICC	Intelligent Cruise Control
ID	Identification
IIHS	Insurance Institute of Highway Safety
IRB	Institutional Review Board
MARTA	Metropolitan Atlanta Rapid Transit Authority
MMUCC	Model Minimum Uniform Crash Criteria
MPH	Mile(s) Per Hour
MPH/S	Miles Per Hour Per Second
MUTCD	Manual of Uniform Traffic Control Devices
NASS	National Accident Sampling System
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NIH	National Institute of Health
NMSL	National Maximum Speed Limit
NOAA	National Oceanographic and Atmospheric Administration
OBD	On-board Diagnostic
OCGA	Official Code of Georgia
PDOP	Positional Dillution of Precision
PDPS	Problem Driver Pointer System
PSL	Posted Speed Limit
RC	Roadway Characteristics
RDC	Regional Development Center

SMARTRAQ	Strategies for Metropolitan Atlanta Transportation and Air Quality
SMS	Short Message System
SSS	Sensation Seeking Scale
SUV	Sport Utility Vehicle
TADRA	Teenage and Adult Responsibility Act
TCMS	Traffic Court Management System
TDMA	Time Division Multiple Access
UGA	University of Georgia
USC	United States Code
VIN	Vehicle Identification Number
VMT	Vehicle Miles of Travel
VSS	Vehicle Speed Sensor

SUMMARY

Previous research regarding the relationship between speeding behavior and crashes suggests that drivers who engage in frequent and extreme speeding behavior are over-involved in crashes. However, many of these earlier studies relied on estimates of prevailing and pre-crash speeds, and as a result, their conclusions have been questioned. Over the last several years automotive manufacturers have begun installing airbag systems that collect and maintain accurate pre-crash speeds. Though, patterns of driver speeding behavior are also necessary to discern whether drivers who regularly participate in speeding have increased risk of crash involvement.

This dissertation presents a framework and methods for quantifying and analyzing individual driver behavior using instrumented vehicles. The goals of the research were threefold: 1) Develop processing methods and observational coding systems for quantifying driver speeding using instrumented vehicle data; 2) Develop a framework for analyzing aggregate and individual driver speeding behavior; and 3) Explore the potential application of behavioral safety concepts to transportation safety problems. Quantitative assessments of driver speeding behavior could be used in combination with event data recorder data to analyze crash risk. Additionally, speed behavior models could aid in the early identification of problem behavior as well as in the development of targeted countermeasure programs.

For this research, 172 instrumented vehicles from the Commute Atlanta program were utilized to collect individual driver speeding behavior. Continuous monitoring

capabilities allowed the capture of speed and location for every second of vehicle operation. Driver speeds were then matched to road networks and subsequently to posted speed limits using a geographic information system. This allowed calculation of differences between the drivers speed and posted speed. Several processes were developed to assess the accuracy and the completeness of the data prior to analysis. Finally, metrics and analysis frameworks were tested for their potential usefulness in future behavioral risk analysis.

The results of the research were both positive and staggering. On average, nearly 40% of all driving activity by the sample population was above the posted speed limit. The amount and extent of speeding was highest for young drivers. Trends indicate that speeding behavior decreases in amount and extent as age increases.

Chapter One

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) reported that speeding was a contributing factor in 31% of fatal crashes, claiming 13,380 lives in 2003. Speeding, driving under the influence, and non-use of seatbelts are all behaviors that are over-represented in fatal crashes. Despite mandatory laws to control driving behavior, the motoring public continues to place themselves and others in great danger by participating in these behaviors. Previous research (DeSilva, 1940; LeFevre, 1954; Solomon, 1964; Munden, 1967; Cirillo, 1968; West and Dunn, 1971) suggests that drivers who engage in frequent and extreme speeding behavior are over-involved in crashes. Kloeden, McLean, and Glonek (2002) state that the relative risk of being involved in a casualty crash approximately doubles for each 3.1 mph increase in free traveling speed at posted speeds of 37.2 mph. Their research suggests that reductions in driver speeding behavior could provide substantial reductions in casualty crashes as well as reductions in injury and property damage only crashes.

Unfortunately, many of the earlier studies relied on estimates of prevailing and pre-crash speeds, thus reducing their soundness. It is true that a reduction in speed will reduce the forces at impact during a crash; however, what is still unknown is whether speeding behavior leads to increased crash risk. To solve this problem, one must know something about the general speeding behavior of the driver, as well as the speeding behavior prior to a crash. The purpose of this research is to develop a framework and methods for

quantifying and analyzing individual driver behavior using instrumented vehicles. This type of empirical resource for speeding behavior could be used in combination with data from event data recorders to answer the question of whether speeding behavior increases the risk of crashing. Additionally, it could be used to aid in the development of countermeasure programs specifically designed and targeted to control extreme speeding and other driving behaviors that have been identified as contributing factors to crash occurrence, crash severity, and injury outcomes.

The basis for the framework and methods developed in this research are derived from the field of psychology, specifically applied behavior analysis. Komaki, Barwick, and Scott pioneered the research in behavioral approaches to safety in 1978. Their techniques have been refined and implemented (Sulzer-Azaroff and Santamaria, 1980; Babcock et al., 1992; Ludwig and Geller, 1997; Geller, 1998; Miller, 1998) in numerous environments over the last couple of decades with impressive safety performance improvements. Essentially, behavioral safety approaches involve:

1. Defining desired safe behaviors through direct observation and accident reports;
2. Developing methods and observational coding schemes for observing behaviors;
3. Observing behavior and quantifying safe/unsafe or at-risk behavior at baseline;
4. Intervening to modify at-risk behavior;
5. Monitoring and evaluating changes in safe behavior performance; and
6. Providing feedback.

The key to the success of these programs is that behaviors known to contribute to accidents are identified, observed, measured, and reduced by various means of intervention prior to the occurrence of further accidents. In their ground-breaking study (1978), Komaki,

Barwick, and Scott noted safe performance change in one group from a baseline value of 70% to 90% after intervention, and similarly from 78% in another group in baseline to 99.3% after intervention.

Behavioral-based safety programs operate based on measuring and monitoring safe behavior performance. To understand safe behavior, it is critical to define unsafe or *at-risk* behavior. Krause (1997) defines at-risk behavior as behavior that has been identified as critical to safe performance, such as putting on goggles before beginning an experiment in a chemical laboratory. In this scenario, the lack of putting on goggles before an experiment would constitute an instance of at-risk behavior; whereas, applying goggles would constitute safe behavior performance. By defining and educating workers on proper behavior, companies can observe and measure safe behavior performance and take action when workers do not perform properly. A multitude of opportunities exists for intervention, and researchers have developed multi-level techniques to reach even the most difficult behavior populations. Note that these intervention techniques primarily focus on positive reinforcement such as training, feedback, and incentives for safe behavior performance.

The application of behavioral-based safety principles to motor vehicle safety is somewhat more complicated. For starters, it is difficult to observe individual driving behavior. Secondly, due to the random nature of crash events and the speed at which they occur, reliable human observation and recollection is rarely available. Therefore, the definition of critical unsafe or at-risk behaviors has typically been a subjective task completed by police officers at the time of crash reporting. Post-hoc crash reconstruction

is also used, although it is difficult to discern the exact element (behavior or other) responsible for causing the crash – especially when the reconstruction activities are undertaken months or even years after the actual crash occurrence. Nevertheless, the only way to prevent crashes is to understand what happens *prior* to the crash event.

Given decades of crash data, researchers have identified numerous behaviors that are critical to safe performance including observance of posted speed limits, maintenance of safe following distance, effectively signaling intentions to change lanes, and many more. In the last ten years, there have been over 76,000,000 (seventy-six million) reported crashes in the United States, and of these, nearly 25,000,000 involved injuries (NHTSA, 2004a). The most bothersome statistic, however, is that we have lost 445,413 lives in fatal crashes in this ten-year period. During this time-period, speeding has consistently been cited as a contributing factor in approximately 30% of all fatal crashes. Almost 150,000 fatal crashes have been wholly or partially the fate of speeding behavior. Due to its contribution to crash severity and injury outcomes, speeding behavior has been targeted as the focus of this dissertation.

Research Methods

Typical behavioral safety programs have been implemented in industrial, mining, and construction industries where multiple personnel work together and the observation task can be incorporated into the normal course of work. In motor vehicle transportation, the observation task is much more difficult to undertake since driving is generally an individual task. To date, researchers' observation and measurement of driver behaviors have been limited primarily to human observation, self-report, and electronic recording of

behaviors in a research vehicle. There are issues with the use of each of these techniques. Human observers are expensive to employ, and are prone to error. Self-reports are subject to bias, both upward and downward, in comparison to others depending on the behavioral topic. The use of instrumented research vehicles is potentially the most objective of these observation techniques, but driver behavior may change in an unfamiliar research vehicle and the test route may not necessarily reflect typical driving environments.

Recent advances in in-vehicle instrumentation now allow cost-effective minimal form-factor means of monitoring driver behavior. The reductions in cost and size make in-vehicle instrumentation a viable solution for monitoring driver behavior within the drivers own vehicle. This type of observation has several distinct advantages over previously used methods of observation including:

1. Removes requirement of expensive labor and can be fully automated;
2. Allows for objective measurements made by equipment vs. observer measurements which are prone to error;
3. Allows for monitoring transparency since observers are not present and observation bias is thus reduced;
4. Eliminates self-report bias;
5. Provides continuous monitoring and recording capabilities versus sampling techniques used during human observation, thus allowing complete capture of exposure information;
6. Allows spatial analysis through capture of latitude and longitude from a geographic positioning receiver that can be related to environmental characteristics through a

geographic information system (i.e., captures when, where and how a person drives); and

7. Permits the capture of data in the most naturalistic of driving environments.

For this research, instrumented vehicles were utilized to collect individual driver speeding behavior. Continuous monitoring allowed the capture of speed and location for every second of vehicle operation. Driver speeds were then matched to posted speed limits using a geographic information system to discern differences between the drivers speed and the posted speed. Several processes were developed to verify the accuracy and the completeness of the data before analysis. Finally, metrics and analysis frameworks were tested for their potential usefulness in future risk analysis.

Scope

The research summarized in this document utilizes data collected from vehicles instrumented in connection with the Commute Atlanta research program. Georgia Tech researchers designed the Commute Atlanta Program to directly evaluate consumer response to converting fixed automotive insurance costs into variable driving costs, and begin collecting the actuarial data necessary to forge the links between driver activity, on-road behavior, and crash risk.

Approximately 494 households from the 13-county metropolitan area of Atlanta, Georgia were initially recruited to participate in the Commute Atlanta study. Of these, 268 volunteer households allowed the research team to install a GT Trip Data Collector in each household vehicle driven more than 3,000 miles per year. Instrumentation deployment began in July 2003 and continued through January 2004. In total, 487 instrumented

vehicles are currently included in the study. The GT Trip Data Collector allows researchers to remotely monitor the travel patterns of these vehicles, uploading vehicle and engine operating data via a cellular connection. To establish baseline travel patterns, the research team monitored the driving patterns of the Commute Atlanta pool of household participants for one year with no pricing treatments. Two-weeks of data from the baseline period (March 8 – 23, 2004) were selected for use in this research.

The targeted critical behavior identified for this dissertation is speeding, and therefore, ‘safe performance’ is based on driving within the confines of the posted speed limit (or legislated enforcement limits). The first step in the research process is the development of methods and coding systems for observing driver behavior. To determine speeding behavior, second-by-second driver speed was matched to roadway characteristics, most importantly the posted speed limit. A taxonomy was developed for analyzing speeding behavior and includes definitions for limit-based speeding, non-compliant speeding, constrained speeds, speeding opportunity, etc. Incorporated in the processing section is an analysis of measurement accuracy as well as quality analysis and quality control of associated geographic and road characteristics data. Summaries of driver trip data provide the amount and distribution of vehicle operation in excess of the posted speed limit as well as the mean deviation from the posted limit. The research also presents several metrics for portraying driver speeding behavior. These include histograms of vehicle operation within 5 mph speed bins, Watson plots of vehicle activity by speed and acceleration, and calculations of percent compliance which are similar to percent safe score used widely in behavioral-based safety.

The research summary continues with an assessment of speeding behavior within the instrumented vehicle population. A thorough presentation of the trends apparent in the data was derived using descriptive statistics such as box plots, error bar charts, histograms, and cross tabs. A relationship was sought between speeding and driving conditions or driver characteristics. Given the complex nature of driver speeding behavior, and the influences of roadway and traffic, several methods for quantifying speeding behavior were analyzed. To begin, regression trees were used to identify logical groupings of data by several trip and driver characteristics. Logistic regression techniques were then used to explore potential models for speeding behavior, at the facility, trip, and driver levels. Several driver speeding behavior case studies are included along with one crash-involved driver case study. Finally, the results of the speeding behavior assessment are used to recommend potential directions for future research.

Research Contributions

This research contributes in a number of ways to the advancement of transportation safety analysis. First, it steps outside the bounds of traditional automotive and roadway engineering failure analysis to explore the use of behavioral safety techniques for analyzing driver behavior. Second, this analysis methodology changes the focus from counting crashes to quantifying precursor behaviors. The ability to quantify precursor behaviors would eliminate the need to wait until a crash has occurred to intervene and modify problem behavior. Early detection and intervention techniques for problem behavior have been highly effective (nearly full elimination of accidents) within industrial settings. Third, this research relies on instrumented vehicle technologies to collect accurate detailed data on driver speed behavior and exposure. This type and magnitude of data collection are

unprecedented. Fourth, the study area for the data collection is primarily urban, whereas most previous research on speeding behavior focused on rural areas. Fifth, this research resulted in the development of an analytical framework and data collection techniques that can be used to study other driver behaviors such as seat belt usage, car following, and turn signal usage. These represent other examples of behavior noted in the literature review as contributing to a large number of crashes, injuries and fatalities. Finally, this research allows the quantification of speeding behavior at the individual level based on complete speed and exposure information.

Overview of Research Document

The remainder of this document includes a background section, review of pertinent literature, overview of behavioral safety programs, data sources and data collection, data processing and quality control, sample selection, data analysis, results, and conclusions.

Chapter Two

BACKGROUND

The Speeding Problem

In March 2000, the Atlanta Journal Constitution (AJC) published a five-part series on speeding in Atlanta entitled, “Pedal to the Metal”:

Atlanta’s highways have become rolling crime scenes – places where hardly anyone obeys the law. With traffic jams so often making us late for work, for day care, for flights at Hartsfield [airport], we seem determined to make up for all that lost time whenever the highways allow it. We’ve become the city too busy to brake. What’s the problem with that? It’s maiming and killing us every day.

The series included an analysis of speeds obtained from the Georgia Navigator advanced traffic management system for several interstate locations. The results showed that 75 to 97 percent of all driving at these locations were above the posted speed limit, with up to 30 percent in excess of 15 mph over the speed limit. On an average day in Georgia, there are more than 800 crashes, producing 364 injuries and 4 deaths (GDMVS, 2003). Two-thirds of the people that die in these crashes are not wearing seat belts. One-quarter of the crashes involve speeding.

The National Highway Traffic Safety Administration (NHTSA) reports “speeding is one of the most prevalent factors contributing to traffic crashes. The economic cost to society of speeding-related crashes is estimated...to be \$40.4 billion per year (\$78,865 per minute, \$1,281 per second) (NHTSA, 2004b). In 2003, speeding was a contributing factor in 31 percent of all fatal crashes, and 13,380 lives were lost in speeding-related crashes” (NHTSA, 2004b). Although the overall fatality rate per million vehicle miles traveled has

been on a mild decline over the last ten years, the percentage of speeding related fatal crashes has remained virtually unchanged with a slight increase in the last few years. Of the population involved in speeding related fatal crashes, young males are the most likely to be speeding. In Georgia alone, there were 186 fatalities between the ages of 15 and 19, representing slightly over 12% of the total fatalities (GDMVS, 2003). The relative proportion of speeding-related fatal crashes to all fatal crashes declines as driver age increases (see Figure 1) even as miles traveled increases. Note that the young driver population in Figure 1 is split into two groups, drivers age 15-19 and 20-24. Both groups are over-represented in fatal crashes; however, there are several differences between these groups in terms of their involvement in fatal crashes and other crashes. For instance, drivers age 15-19 are more likely to die in speeding related fatal crashes, while drivers age 20-24 are more likely to die in alcohol related fatal crashes. Regardless of the prevalence of speeding in crash contributions and its effect on our youth, when reviewing the top-priorities of NHTSA, speed is not among them. Instead, NHTSA's Administrator, Dr. Jeffrey Runge (Runge, 2003), lists: 1) increased safety belt use, 2) reducing impaired driving, 3) improving data, 4) reducing rollovers, and 5) improving vehicle compatibility.

Setting and Enforcing Limits

One of the reasons why the nation's transportation safety administration is not targeting speeding is because setting and enforcement of speed limits is the responsibility of the states. This has not always been the case. In 1974, Congress passed a national maximum speed limit (NMSL) of 55 mph in response to fuel shortages. In the year following the enactment, highway fatalities dropped by 16 percent. This was the single largest reduction in highway deaths since World War II. In 1978, Congress passed

additional legislation that required compliance with the 55 mph limit, with non-compliance subject to sanctions. However, no states ever lost funds. In 1987, Congress enacted legislation that allowed states to raise speed limits to 65 mph on rural interstates (federal sanctions only applied to 55 mph limits). In 1991, Congress changed the compliance legislation to cover both 65 and 55 mph limits. Under the new law, states would not lose funds but rather the state's highway safety program received the funds. After 20 years of federal involvement in speed setting and compliance, Congress repealed the NMSL in 1995. In the hands of the states, maximum speed limits increased to as much as 75 mph. Currently, 12 states have a maximum speed limit of 75 mph, 20 states have maximum of 70 mph, and the remainder have a maximum of 65 mph with the exception of Hawaii, which has a 60 mph maximum speed limit.

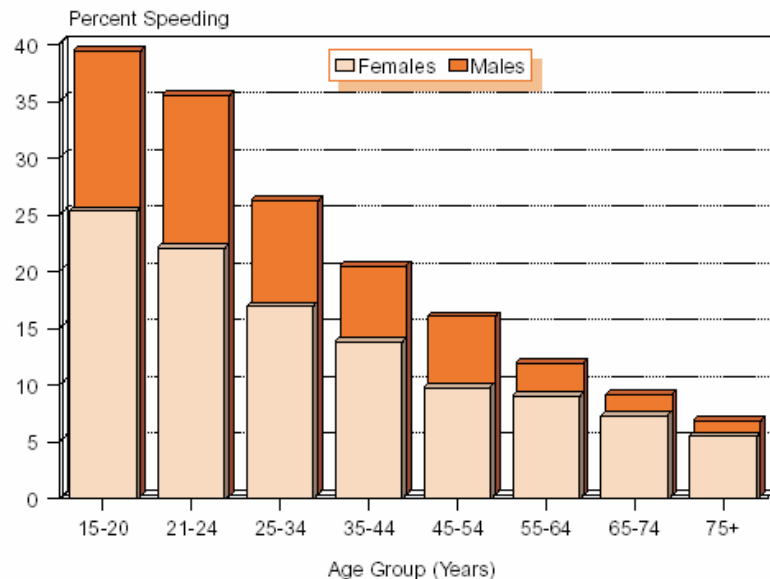


Figure 1 Percent of Fatalities within Each Age Group with Speed as a Contributing Factor (Source: NHTSA, 2004)

The maximum speed limit in Georgia is 70 mph. The Georgia legislature adopted language from the Uniform Vehicle Code for absolute speed limits, meaning that exceeding the speed limit is illegal *per se* regardless of whether or not it is safe. This means that a Georgia State Trooper could issue a citation for exceeding the maximum speed limit of 70 by only one mile per hour. However, the legislated penalty structure does not support such a citation in and of itself. The monetary fines and points assessments for speeding violations are shown in Table 1. Exceeding the posted speed limit is only fined when speeds are greater than 5 mph above the limit (O.C.G.A. § 40-6-1 (2003)). In addition, Georgia legislators subsequently introduced leniency in the enforcement of speed limits on all roads by writing a series of laws making it difficult for local police to write speeding tickets (O.C.G.A. § 40-14-8 (2003)). For example, even when using radar and laser equipment, local police cannot ticket a speeder unless he/she is in excess of 10 mph above the speed limit. The consequence of being cited for speeding 10 mph over the speed limit in Georgia carries a maximum fine of \$25 and no points accumulated against the license of the driver. This is not specific to Georgia, other states also have lenient enforcement policies (see Carr, n.d.).

In the March 5, 2000 Atlanta Journal Constitution series on speeding in Atlanta, the AJC reported that Atlanta police wrote 17,000 tickets for speeding in 1998 (approximately 46 speeding tickets per day). At one freeway monitoring station on I-20 near the downtown connector, the 24-hour traffic count reached 78,762. The AJC observed speeds greater than 15 mph above the speed limit for 23% of the drivers. If enforcement ticketed each of these drivers for their traffic violation, 18,115 drivers would have received tickets with fines between \$125 and \$500 as well as a minimum of 2 points and a maximum of 6

points toward revocation of their license. These citations would provide a minimum of \$2,264,375 in revenue generation. In one day, in one single location, more drivers unlawfully exceed the speed limit without consequence than the number ticketed in metro Atlanta on a yearly basis. The odds of receiving a ticket for speeding are seemingly similar to those of winning the lottery.

Table 1 Georgia Maximum Penalties for Speeding Citations

Amount exceeding Posted Speed Limit	Maximum Fine (up to...)	Points against License
<= 5 mph	\$0	0
>5 and <= 10 mph	\$25	0
>10 and <= 14 mph	\$100	0
>14 and <= 19 mph	\$125	2
>19 and <= 24 mph	\$150	3
>24 and <= 34 mph	\$500	4
>34 mph	\$500	6

However, legislators and enforcement agencies are not the only ones to blame for the prevailing speeding behavior. Engineers also play a role. In the design of roadways, there are specific requirements for minimum safe stopping and passing sight distances and minimum curve radii, but they are just that – minimums. Over the years, engineers have continually over-designed roadways when economically and geographically possible. By selecting a minimum safe radius and then using any feasible radius larger than this in design, engineers have essentially designed and built a roadway network with design features that have no real continuous link to design speed or posted speed limits. As such,

drivers have learned that they can exceed the posted speed limit on many roads without consequence.

The Insurance Institute for Highway Safety (IIHS) monitors travel speeds in New Mexico on a yearly basis. Researchers found that speeds increased incrementally above the posted speed limit until the repeal of the national maximum speed limit in 1995, at which time the speed limit increased and speeds also sharply increased and still continue to increase today (IIHS, 2003). Adding to this the actions of the legislature, the effectual posted speed limit is 10 mph higher and maintains little if any of the intended safety margin.

Developments in Transportation Safety

The notion of transportation safety implies crash prevention and thus protection from loss of life, limb, and property. Over the years, many transportation safety programs have focused evaluations on the study and measurement of crashes and severity. By examining the crashes, engineers seek to find causal elements of crashes and strive to change roadway and vehicle design to account for additional safety margins. Petroski defends this type of analysis and re-engineering in his 1985 book, *To Engineer is Human:*

The Role of Failure in Successful Design, by stating:

I believe that the concept of failure ... is central to understanding engineering, for engineering design has its first and foremost objective the obviation of failure. Thus the colossal disasters that do occur are ultimately failures of design, but the lessons learned from those disasters can do more to advance engineering knowledge than all the successful machines and structures in the world. Indeed, failures appear to be inevitable in the wake of prolonged success, which encourages lower margins of safety. Failures in turn lead to greater safety margins and, hence, new periods of success. To understand what engineering is and what engineers do is to understand

how failures can happen and how they contribute more than successes to advance safety.

In essence, engineers, as well as the motoring public, have generally accepted the fact that failures occur. Sometimes attributed to chance or destiny, these failures are producing injuries and fatalities in epidemic proportions. However, the individual and random nature of these tragedies does not elicit the same reaction of less fatal failures such as the destiny of Flight 800 or the Hindenburg. In comparison, the total fatalities occurring between the Hindenburg, Titanic, Pearl Harbor, Oklahoma City Bombing, Flight 800, September 11th, and the Columbine Shootings do not even account for a fraction of the fatalities produced by the surface transportation system in one year.

During the early years of the massed produced automobile, the focus of the blame for failures was placed on the driver. Safety organizations, backed by the automotive industry pushed driver training, and educational efforts. In 1965, Ralph Nader wrote a controversial book, “Unsafe at Any Speed,” that uncovered the travesties occurring in the automobile industry. Despite information regarding automobile defects and potential life saving devices, the automobile industry continued the focus on the driver.

For decades the conventional explanation [for the occurrence of crashes] preferred by the traffic safety establishment and insinuated into laws, with the backing of the auto industry and its allies, was that most accidents are caused by wayward drivers who *ipso facto* cause most injuries and deaths. With the reputation of publicity themes about the ‘nut behind the wheel’, industry and its captive safety councils bombarded public consciousness into believing that bad drivers were the cause and good drivers the solution. Not only was their approach unscientific regarding drivers, but it conveniently drew attention away from the already available or easily realizable innovations that could be incorporated into vehicle and highway design to minimize the likelihood of a crash and to reduce the severity of injuries if a crash should occur.

In 1966, President Johnson signed the Motor Vehicle Safety Act (15 U.S.C. §§ 1381-1431) bringing the unregulated automobile industry under law. The National Highway Safety Bureau (later NHTSA) led by Dr. William Haddon set standards requiring laminated windshields, collapsible steering columns, seat belts, and subsequently shoulder harnesses. These standards brought with them dramatic changes in vehicle safety, but not reduction in crash frequency. A medical doctor and epidemiologist by training, Haddon had certain beliefs about what could effectively bring about reductions in crashes. Haddon believed that the best safety measures are passive. In the medical field, doctors can eliminate measles by vaccination and typhoid fever by chlorinating water. Haddon was convinced that the air bag would be the automobile transportation ‘vaccination’. While it has saved numerous drivers from casualty, it has not stopped crashes from occurring.

Three Components

There are three components in the transportation system – the roadway, the vehicle, and the driver. Following Haddon’s lead, much of the safety research has focused on the vehicle and the roadway and relatively little research has been conducted over the last several decades to study the human behavioral components of crashes (i.e., speeding, following too closely, inattention, disregard of safety devices and operating regulations, driving under the influence, etc.). Instead of dealing with these behaviors, engineers have focused upon engineering around them. For example, new Intelligent Cruise Control (ICC) systems maintain appropriate following distances for the driver by speeding up and slowing down automatically based on forward seeking radar technologies. The anti-lock brake system (ABS) allows the driver to remain in control of the vehicle direction in a locked brake situation – allowing better handling in extreme maneuvers from unsafe behaviors

such as following too closely or driving too quickly. Traffic engineers have also designed the roadside to be more forgiving in crash scenarios: guardrails keep vehicles from exiting the roadway onto non-traversable terrain, cross-bucks stop drivers from crossing railroad tracks in front of oncoming trains, and crash cushions placed at bridge piers and elsewhere soften the crash forces when drivers crash into them. Cognitive and engineering psychologists have contributed greatly to the fields of signage, markings, and cockpit design. However, contributing factors relating to what the driver is actually doing in the vehicle received little attention. Due to inadequate accident reporting forms, investigative techniques, and data sources, researchers garner little information from these accidents to stem recurrences of the behavioral component. Further, there is a common opinion among engineers that behaviors cannot be changed, thus they tend to be ignored.

This research steps outside the bounds of traditional automotive and roadway engineering failure analysis to explore the use of behavioral safety techniques for analyzing driver risk-taking behavior. By doing so, the methodology changes the focus from counting crashes to quantifying pre-cursor behavior. Crashes are easy to identify and therefore have been the focus of safety research for many years. However, centering attention on the crash as the primary item of interest “impedes the application of more useful information contained in the magnitudes of unsafe behavior performance that precedes the accident” (Krause, 1984).

Issues Regarding Human Behavior

Transportation safety is a vicious cycle: engineers design cars and build roadways, humans drive the cars on the roadways, humans crash the cars on the roadways, engineers

design more safety features into the vehicles and roadway, and yet more crashes. Wilde (2001) developed a theory of risk homeostasis that drivers have a certain amount of risk that they are willing to accept – as safety devices are added to vehicles, drivers will actually compensate by participating in other risk-taking behaviors thus maintaining the original level of risk prior to the addition of the safety device. The theory is quite controversial, but one that nonetheless should be addressed. The obvious component of this theory is that engineering advancements will not provide the desired results without parallel changes in driver behavior.

Driver behavior is a complex phenomena developed over a number of years – the complete influences on which would be impossible to determine without observing a person's behavior over their entire lifetime. Parental monitoring (Shope et al., 2001), restriction (Hartos, 2002), and rulemaking (Beck, 2001) were studied with regard to their effect on driving after licensing. These types of parental involvement are positively related with lower crash and conviction rates as well as less risky driving. Additionally, parental influence in the development of young driver behavior may also come in the form of genetics and model behaviors. In principle, parents may pass down genetic traits such as temperament (Cloninger, 1994; Koopmans et al., 1995) or aggressiveness (DiLalla, 2002). By observation beginning at a very early age, children learn by model behavior displayed by the parent. Children perceive the driving style and interactions with other road users over a number of years. Bad habits exhibited by parents can be learned through model behavior. In 2001, Ferguson et al. found that parents driving records were predictive of their children's records. Parents' crashes and parents' convictions predicted children's convictions. However, these predictions may also be reflective of exposure and

socioeconomic variables (Bianchi and Summala, 2004). It is not impossible, however, to change behavior. Smokers can become non-smokers, alcoholics can become sober, drug-addicts can stop using, over-eaters can lose weight, and speeders can slow down.

Behavioral Safety

Overall, the 3E's (Engineering, Enforcement, and Education) have not been effective in promoting safe driving speeds. To establish behavior, antecedents must be present, and consequences must be immediate and tangible. In the area of transportation, there are many well-established behaviors with immediate and beneficial consequences. Unfortunately, most of them are not considered to be safe behaviors. Take for example a driver approaching a traffic signal displaying an amber light. The antecedent in this scenario is the traffic signal changing to amber, a typical behavior in congested urban areas is a hard acceleration (to allow the driver to speed through the intersection before red), followed by a rewarding consequence in that the driver avoided the signal delay. In a large urban area where traffic delays are third largest in the nation (Schrank and Lomax, 2004), drivers assume numerous bad habits in the sake of shaving mere seconds from their travel time. Speeding, following too closely, excessive and abrupt lane changing, running amber signals (as well as red ones), and rolling through stop signs are examples of these poor driving habits. These include the top three behavioral contributors to crash events: following too closely, failing to yield, and speeding.

Behavioral safety programs seek to identify behaviors contributing to accidents and define contingencies to eliminate and replace those unsafe behaviors. In doing so, psychologists seek to determine functional or systematic relationships between the

environment (or antecedents), the behavior, and the consequences (positive or negative) that occur immediately after performance of the behavior. The actual determination of unsafe behaviors that will lead to accidents is a very difficult task. The likelihood that a single unsafe behavior will cause an accident is left to mere chance. Most will not dispute, however, that increases in the frequency of unsafe behavior will lead to increases in accidents. The opposite is true too – decreases in unsafe behavior should also decrease accidents (Krause, 1984). In this respect, behavioral safety techniques have potential to produce successful driver safety programs. The challenge is to identify and substantiate the unsafe driving behaviors that lead to crashes. A full manuscript on behavioral safety methods and applications to transportation safety problems can be found in Appendix A.

For many years, researchers studied the role of speed in crashes. There is no question speeding contributes to the severity of crashes. In fact, many studies on the role of speed in crashes have focused specifically on the fatalities. The laws of physics and human ability provide the basis for increases in crash severity with increases in travel speed. Excessive speed generates forces that man nor machine can overcome (see Figure 2). Solomon (1964), Munden (1967), and others concluded that an individual's variance from mean travel speed was an important factor in crashes, and this finding has continued to provide direction for research on the relationship between speed and crash involvement.



Figure 2 Speed-Related Fatal Crash Involving a Mitsubishi Eclipse
(Source: <http://need4speed.ws>)

Few researchers have attempted to determine how the choice of speed made by each driver affects the crash risk of that driver. Those that attempted to make this correlation did not have complete exposure information (total time spent driving on a given road type and under a specific posted speed limit). Instead, previous research generally relied on speeds taken at a single location with little representation from varying road classes. Many questions remain:

- Are drivers who engage more frequently in speeding behavior over-involved in crashes?
- Are drivers who engage in extreme speeding more likely to be involved in crashes?
- Are speeders and non-speeders similar in all other respects?
- What are the characteristics of drivers who exhibit frequent or extreme speeding behavior?

- On what types of facilities does speeding behavior occur?
- According to citations, young males are the most prominent speeders – are relationships, such as this, supported by continuously observed speeding behavior?

Although the sample is not sufficient to fully answer the remaining research questions regarding the relationship between speed and crash probability, the methods are transferable for use in larger studies.

Chapter Three

LITERATURE REVIEW

This chapter describes the problems associated with driver speeding behavior. The key word here is *behavior*. The road does not control speed. The vehicle does not control speed. The driver controls speed, and therefore speeding is a behavior of the driver. By definition, behavior is everything that a person does that is observable and measurable (Myers, 1977). To teach a person a new behavior, you must begin by specifying an action that you could see or hear him/her do. One of the basic assumptions of behavior management is that behavior is learned. Persons learn to behave by the consequences within their environment; therefore, in order for a person to learn to behave differently, consequences or perceived consequences for a behavior must be changed. Short of requiring speed governors on all vehicles, behavior modification is required to control driver speeding and the resultant effects on crashes.

The review of literature also depicts the difficulties associated with studying the relationship between speeding behavior and the incidence of crashes. In general, the results of previous research have shown a positive relationship between speeding behavior and increased involvement in crashes. However, difficulties in collecting appropriate and accurate data raise several concerns about the validity of the results obtained in previous studies. Some researchers (Hauer, 1971; White and Nelson, 1970) have even insinuated that the resulting functional forms of models portray the error in the measurements rather than the relationship with between study elements. Despite the concerns with previous research results, there are several known elements of speed-related crashes. The physical

laws of speed inherently contribute to decreased reaction time, increased crash forces, and increased injury/casualty potential when a speeding driver encounters a crash scenario. It follows then, that if it were possible to modify driver behavior to reduce speed, drivers would have more time to react to events possibly avoiding crashes, and if the crash were unavoidable, then reduced speeds would reduce crash forces and injury potential thereby reducing damages and injuries associated with the crash.

A study of driver speeding behavior requires background knowledge regarding the physical aspects of speed, the interactions of the driver-roadway-environment, principles of behavior, and the laws governing such behavior. Therefore this review features an array of topics including:

- Definition of speed and speeding,
- The physics of speed and crashes,
- Relationship between speed and crashes,
- Relationship between speed and speed limits,
- Crash-involved driver demographics,
- Driver behavior,
- Regulatory environment,
- Infrastructure Characteristics, and
- Data.

There are nearly as many definitions and interpretations of what is speed and speeding as there are factors relating to crashes. The literature review commences with a set of published definitions. The prevalence of speeding has given rise to debates on the

topic. Many people believe emphatically that drivers can speed and still be safe drivers. Others believe that the variance in speed on the road is the greatest contributor to crashes. The lack of uniform definitions for speed and speeding, as well as the lack of precise scientific measurements, have hampered development of conclusions regarding the risks of speeding.

True experiments in the study of speed and crashes have been few. Most studies are observational in nature and are either cross-sectional, longitudinal, or before/after in the case of interventions. Many of these studies have focused on actual crashes and have used post-crash reconstruction techniques or police reports to discern speed contributions to the crash outcome. A few researchers have tried to relate the difference between case-control prevailing speeds and estimated pre-crash speeds. Considerably fewer studies have been conducted to evaluate how the choice of operating speed made by each driver affects the accident involvement of that driver. This document highlights the outcomes of the research previously conducted along with some of the common problems associated with validity of the outcomes.

The focus of this research is the accurate measurement and quantification of driver speeding behavior. Regardless of whether a driver is at a higher-risk of involvement in a crash if he/she speeds, crashes involving speeding drivers have proven increases in crash force, damage, and injury. As history has shown, driver behavior has positively changed with a number of safety interventions. Overall safety belt use rose from 58% to 75% between 1994 and 2002 (NHTSA, 2002). NHTSA (2002) estimates that seat belts saved 147,246 lives between 1975 and 2001. Child restraint use rates are increasing, and helmet

use among bicyclists is rising (NHTSA 2002). Most of these results are generally attributed to changes in legislation and national public education and media campaigns. Unfortunately, the individual states have not effectively organized their efforts to eliminate the dangers of speeding behavior. The bottom line is that behavior can change, but it takes time and effort. Understanding who the target audience is will help determine the most effective intervention strategies.

The use of this research to bring about behavioral changes requires knowledge of behavior modification techniques. Further, general knowledge of driver behavior characteristics (attitude, accident proneness, and risk-taking) is also required. Therefore, included in this review is a section on studies of driver behavior. Following the literature review, a separate chapter defines behavioral-based safety concepts and provides examples of behavioral safety applications in transportation. Behavioral-based safety concepts are paramount to the foundation of this research.

Finally, speeding behavior research without a full understanding of the legal, enforcement, and reporting functions is remiss. Included in the review is a section on Georgia Policy that provides information on available state databases for crashes, citations, convictions, and licensing. In terms of convictions and licensing, the review includes policies regarding the enforcement of speeding. In Georgia, there are no penalties associated with speeding unless the driver is more than 10 mph above the posted speed limit. In terms of speeding behavior, the limited consequences may actually shape speeding behavior.

Defining Speed and Speeding

Fundamental to transportation is the concept of speed. Speed is used as a design criterion, a measure of the level of service, and an operational control. Despite its widespread use, consistent definitions of the terms speed and speeding have historically been lacking. In 1998, the National Cooperative Highway Research Program (NCHRP) funded a research project to study practices regarding design speed, operating speed and posted speeds. The resulting NCHRP Report 504 (Fitzpatrick et al., 2003) covers the evolution of speed definitions in detail. The following table of definitions (Table 2) contains those definitions of speed most recently published in the Manual of Uniform Traffic Control Devices (MUTCD) (2000) and A Policy on Geometric Design of Highways and Streets (AASHTO Green Book) (2001).

Prior to 1998, the term design speed referred to the ‘maximum safe speed’ that can be maintained over a section of highway under favorable conditions. AASHTO removed the term ‘safe’ in 1998 to reflect the recognition that operating speeds and posted speed limits can be higher than the design speed without negatively influencing safety. In setting speed limits, Fitzpatrick et al. (2003) found the 85th percentile to be the predominant means of selecting posted speeds. States reported deviation from using the 85th percentile occurring in relation to political agendas (33%), accidents (13%), roadway area (11%), and roadway geometry (9%) (Fitzpatrick et al., 2003).

Table 2 Definitions of Speed

Measure	Reference	Definition
Operating Speed	MUTCD 2000	<u>Operating Speed</u> – a speed at which a typical vehicle or the overall traffic operates. Operating speed may be defined with speed values such as the average, pace, or 85 th percentile speeds.
	AASHTO Green Book 2001	<u>Operating Speed</u> is the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85 th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature.
85th Percentile Speed	MUTCD 2000	<u>85th Percentile Speed</u> – The speed at or below which 85 percent of the motorized vehicles travel.
Average Speed	MUTCD 2000	<u>Average Speed</u> – The summation of the instantaneous or spot-measured speeds at a specific location of vehicles divided by the number of vehicles observed.
Pace Speed	MUTCD 2000	<u>Pace Speed</u> – The highest speed within a specific range of speeds that represents more vehicles than in any other like range of speed. The range of speeds typically used is 10 km/hr or 10 mph.
Design Speed	MUTCD 2000	<u>The Design Speed</u> is a selected speed used to determine the various geometric design features of the roadway.
	AASHTO Green Book 2001	<p><u>The Design Speed</u> is a selected speed used to determine the various geometric design features of the roadway.</p> <p>Provisions:</p> <ul style="list-style-type: none"> • The assumed design speed should be logical for the topography, adjacent land use, and highway functional classification (paraphrased). • “All of the pertinent features of the highway should be related to the design speed to obtain a balanced design.” • “Above-minimum design values should be used where feasible...” • “The design speed chosen should be consistent with the speed a driver is likely to expect.” • “The speed selected for design should fit the travel desires and habits of nearly all drivers...The design speed chosen should be a high-percentile value...i.e., nearly all inclusive...whenever feasible.”

Fitzpatrick et al. (2003) collected free-flow speed data at a number of sites on various functional classes of roadway. The strongest statistical relationship found is that between operating speed and posted speed limit. Examining different percentiles, correlation significance was high for all percentiles including the 95th, 90th, 85th, 50th, and 15th. In terms of the coefficient of correlation, the 50th percentile model had the best results ($R^2 = 0.911$) – reflecting that the posted speed is closest to the 50th percentile speed. Fitzpatrick et al. developed a regression equation for the 85th percentile speed as $Q_{85} = 7.675 + 0.98 (\text{Posted Speed Limit})$. The coefficient for the factor of posted speed limit is equal to 0.98 (very close to one), therefore, the 85th percentile speed increases nearly in proportion with the posted speed limit. Another interesting item is that constant in the 85th percentile regression equation is equal to 7.675, so the estimated 85th percentile speed is over 7 mph greater than the posted speed.

In terms of road class, the posted speed on non-freeways would encompass most drivers if increased by 10 mph. In suburban and urban areas, increasing the posted speed limit by 10 mph would only account for 86 and 95 percent of vehicles, respectively. For low posted speed roads (posted speed = 30, 35, and 40 mph) only 28, 22, and 32 percent, respectively, of vehicles on the road were at or below the speed limit. (Fitzpatrick et al., 2003)

Fitzpatrick et al. (2003) recommended research emphasizing the study of drivers speed choice behaviors. They found that many of the speed distribution plots show three modes, indicating that there are perhaps three types of drivers in terms of speed choice:

1. “Conservative drivers who always try to stay below the posted speed limit,

2. Moderate drivers, who constitute the majority of drivers, who try not to exceed speed limit to unreasonable degrees, and
3. Aggressive drivers, who use posted speed limits as the lower bound and constantly look for opportunities to drive at higher speeds.”

One last defining term is that of speeding. In several recent publications (DOT, 1997; GAO, 2003; FHWA, 2000) from agencies within the Department of Transportation, including NHTSA and Federal Highway Administration (FHWA), all agencies consistently defined speeding as “exceeding the posted speed limits or driving too fast for conditions.” In 1998, the NHTSA completed a national survey of speeding and other unsafe driving actions. Surveyors asked participants about the dangers of speeding 10 mph and 20 mph over the speed limit for various road classes. In general, drivers rated speeding actions as the least dangerous of all actions surveyed. Other actions included tailgating, slow but not complete stop at stop sign, entering an intersection on yellow, making an angry gesture to another motorist, making an illegal U-turn, and excessive lane-changing. The most dangerous driving actions included passing a school bus with red lights flashing and stop arm in view, crossing railroad tracks with active cross-bucks, passing a vehicle in a no-passing zone, driving just under legal alcohol limit, racing another driver, and driving through a stop sign.

The Fatal Analysis Reporting System (FARS) analysts have three criteria for counting a fatality as involving speeding. These include:

- Driver-related factor of driving too fast for conditions,
- Driver-related factor of exceeding the legal speed limit,

- Driver charged with a speeding-related violation (other than driving too slowly), or
- Vehicle speed was at least 10 mph over the legal speed limit.

All of these criteria relate directly to elements of police reporting forms and FARS data collection elements. FARS analysts reported fatality rates per 100 million vehicle miles travel for speeding-related crashes by facility type as 0.28 – interstates, 0.39 – arterials, 0.80 – collectors, and 0.84 – local roads (FHWA, 2000). Despite their low traffic volumes, local and collector roads¹ incur approximately 50% of the fatalities annually. The highest posted speed roadways, interstates, are the safest in terms of fatality rates due to their high travel mileage.

The Physics of Speeding

In 2003, the Insurance Institute for Highway Safety published a question and answer document on speed and speed limits, including a concise description of speeding and crash outcomes. According to the IIHS, there are four basic ways speed influences crash outcome:

1. Speed increases the distance a vehicle travels from when a driver detects an emergency until the driver reacts.
2. Speed increases the distance needed to stop a vehicle once an emergency is perceived.
3. Crash severity increases by the square of the speed so that, when speed increases from 40 to 60 mph, speed increases by 50 percent while the energy released in a crash more than doubles.

¹ Local and collector roads are typically low posted speed roads found in residential and business areas.

4. Higher crash speeds reduce the ability of vehicles, restraint systems, and roadway hardware such as guardrails, barriers, and impact attenuators to protect occupants.” Higher travel speeds increase the risk of serious injury and death when crashes occur. Crash severity also increases disproportionately with vehicle speed.

Using National Accident Sampling System (NASS) data, Bowie and Walz (1994) examined the crash severity relationship for non-fatal injuries using the Abbreviated Injury Scale (AIS). Injuries rank from 1 (minor) to 6 (not survivable). The results show striking increases in injury severity as the change in velocity (deceleration rate) increases. O’Day and Flora (1982) found the same relationship with fatality rates. A driver crashing with an impact speed of 50 mph was twice as likely to die as one crashing at 40 mph. Above 50 mph, the probability of death was greater than 50 percent.

Kloeden et al. (1997) compared crash-reconstruction speeds of 150 cars involved in injury crashes in 37.3 mph speed limits in Australia with free-flow conditions collected in a case-control method. The average and median speed of traffic was 37.3 mph. Vehicles exceeding the 90th percentile speed or traveling more than 4.3 mph faster than the speed limit had above-average injury-involvement crash rates. Nearly 25 percent of cars involved in injury crashes traveled faster than 44.7 mph compared to only 2 percent of the traffic traveling at the same speed.

The Relationship between Speed and Crashes

The National Highway Traffic Safety Administration (2004) estimates that speed is a contributing factor in 31% of all fatal crashes, which translates to 13,380 lives lost in 2003. In addition, tens of thousands more people suffered moderate or critical injuries in

speed-related crashes (NHTSA, 2004). The relationship between travel speed and collision severity is clear: A marginal increase in travel speed leads to a significant increase in collision severity. However, the relationship between speed and collision involvement is more complicated.

DeSilva (1940) completed an early study of speed and crashes in Connecticut. The researchers used road tube speed-meters to detect the speed of passing vehicles. Concealed observers recorded the license plate of each passing vehicle. Further downstream police officers motioned over vehicles passing the observation point for survey administration. Researchers later obtained crash records and matched them back to the drivers. Driver groups included high-speed (speed over the speed limit) and moderate-speed (speed limit to speed limit minus 10 mph). Of 459 drivers, 372 were moderate-speed drivers and 87 were high-speed drivers. On average, the high-speed drivers had 58.7% more accidents than moderate-speed drivers. Unfortunately, this study and many more to follow were plagued by design. The use of convenience sampling and limited representation of roadway facilities limited transfer of results. A secondary problem associated with this method is the exclusion of drivers involved in fatal crashes, of which, a large portion of the fatal crashes are speed related.

In 1954, LeFevre also tried to relate accident experience to speed habits. LeFevre used the same spot-speed approach and recording of vehicle registration to link drivers with crash records. Similar findings resulted from the study, but again the sample and single study location limited the transferability.

In the 1960s and early 1970s, the United States Department of Transportation and transportation research community realized the importance of understanding the relationship between individual driver speed behavior and safety. As a result, agencies funded numerous studies during this time-period leading to the following conclusions:

Solomon (1964) examined the accident reports of vehicles on two- and four-lane rural highways in eleven states. He found that crash rates increased as the reported speed of the vehicle involved deviated from the observed mean speed of the traffic for a given road.

Cirillo (1968) analyzed daytime crashes on Interstates in 20 states. The research only included accidents involving two or more vehicles traveling in the same direction. Again, the results show that the combination of very fast and very slow vehicle speeds is hazardous. The data used to develop these relationships included estimated speeds given on crash reports. The crashes actually occurred several years prior to the development of the associated prevailing speed profiles for the roadways examined.

Munden (1967), using a different approach, obtained results similar to those of Solomon and Cirillo. Munden recorded the speeds of vehicles at 10 sites in England and investigated the crash history of their drivers. He found that drivers who consistently drove much faster or much slower than the mean speed of nearby vehicles had higher crash rates than average speed drivers.

Undoubtedly, the most cited work on speed and crashes is that by Solomon. His research produced the famous U-shaped relationship (Figure 3) depicting deviation from mean speed as the greatest contributor to crashes. For example, cars traveling at 40 or 80 mph where mean speed is 60 mph are more likely to be involved in an accident than those traveling at or near the mean speed. The study site selection limits results to two- and four-lane rural highways.

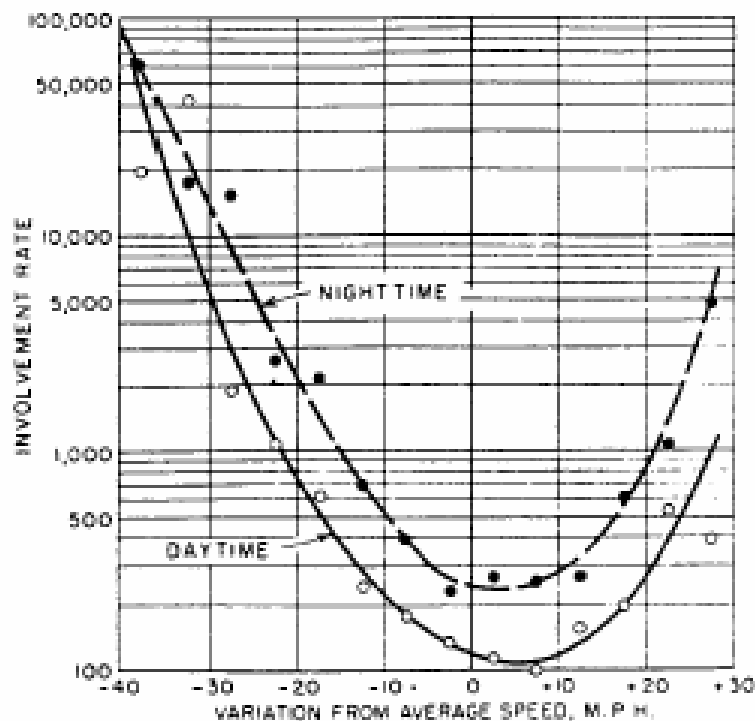


Figure 3 Involvement rate by variation from average speed on study section
(Source: Solomon, 1964)

These previous studies consistently indicated the trend of increased crashes with an increase in speed variance. However, noted limitations in the study designs have lead to questions of accuracy and validity of the data. Due to the cost and deficiencies of previous technologies minimal use was made of instrumented vehicles. The majority of these earlier

studies relied on estimations of pre-crash speed as a basis for their claims. Typically, researchers gathered speeds from police crash reports, self-reporting, witness reports, or crash reconstruction techniques. In some studies, researchers collected estimates of prevailing speeds at the crash sites in a case-control method. The case-control method involves collecting data from the crash site at the same time of day/day of week that the crash occurred. This may vary significantly from the actual time of the crash if there was some abnormal traffic condition present. Figure 4 shows an example of failed data collection using case control methodology. The data in the graph depict prevailing speed distributions along I-10 in San Antonio, TX at the location of a crash involving a GPS instrumented vehicle (Ogle et al., 1998). The speeds reported by the instrumented vehicle indicated that the driver was proceeding in stop and go traffic below 17 mph when the crash occurred. In the 3 weeks following the crash at the same time of day and day of week, no vehicles were observed traveling below 30 mph. In fact, the observations at 30 mph even included a speed reduction caused by rain activity – the rain data would typically not be considered due to the variation in weather from the actual date of the crash. Using these three case controls, one would falsely assume that the vehicle was traveling far below the average speed at the time of the crash, when in actuality, the traffic conditions at the time of crash depict an abnormal congestion occurrence. Obviously, the lack of accuracy in determining pre-crash speed measurements in addition to the lack of accuracy in determining prevailing speeds heightens the problem of obtaining accurate estimates of deviations from prevailing speeds.

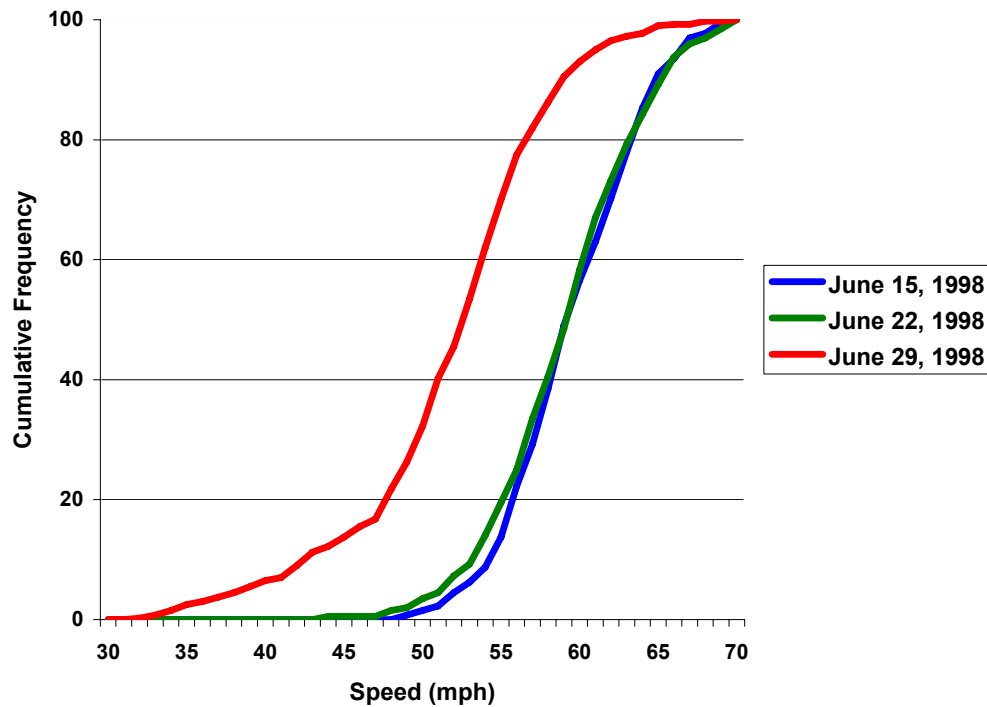


Figure 4 Example of Prevailing Speed Measured in Case-control Method

Elvik (2004) converted the results from several studies (Solomon, 1964; Munden, 1967; Cirillo, 1968; West and Dunn, 1971; and Kloeden et al., 1997) into a common metric. The number of standard deviations from mean indicated drivers speed choice. The study findings agree for all levels of speed except for the lowest speeds. The discrepancy between studies in the lowest speed range was dramatic. Elvik theorized that this discrepancy was an outgrowth of speed estimations and thought that speed at the time of crash was actually lower than speeds during the early development of the crash. Because many drivers may brake prior to crashing, it is obvious that many more crashes occur below average travel speeds.

In the late 1960s, the Research Triangle Institute (1970) investigated 200 crashes occurring on over 70 miles of state roads during a 13-month period. The researchers estimated pre-crash speeds through detailed accident investigations and used loop detectors to monitor speeds along the state highway continuously. Researchers collected speeds at the date and time of crash through stationary sensing, as well as through case-control monitoring at accident locations. The results again show a U-shaped function, but not as pronounced as those found in earlier studies. This may be due to the removal of turning-vehicles from the study. Other items of interest included a speed deviation and age interaction with younger drivers driving at higher speeds.

White and Nelson (1970) reported on the effects of measurement errors in estimating involvement rate as a function of deviation from mean speed. Providing an example of error in the denominator of the involvement rate function based on proportion of travel during different time periods, error in extreme deviation ranged from -81% in the low ranges to +58% in the high ranges. Therefore, when overestimation of total mileage occurs in the extremes, deviation is underestimated in the middle intervals, and overestimated in the outer intervals. The researchers noted the largest error component in all the previous research to be the pre-crash speed measurement error. Errors in estimating pre-crash speeds cause overestimates in the numerator of the involvement rate function in extreme intervals and underestimates near the middle intervals. Assuming accurate reflections of vehicle mileage, this error alone can artificially produce the U-shaped relationship.

Hauer (1971) also offered new cause-effect hypotheses to support the previously found U-shape. Not one of his arguments had any relation to deviation from mean speed, but instead the arguments were based on behavioral factors. For example, he set forth a hypothesis regarding involvement rate and overtaking: “on rural roads between intersections, the probability of accident involvement is closely related to the rate at which overtaking takes place.” Based on a crude model, the shape produced (Figure 5) by the overtaking analysis is similar to that produced by Solomon’s deviation from mean speed.

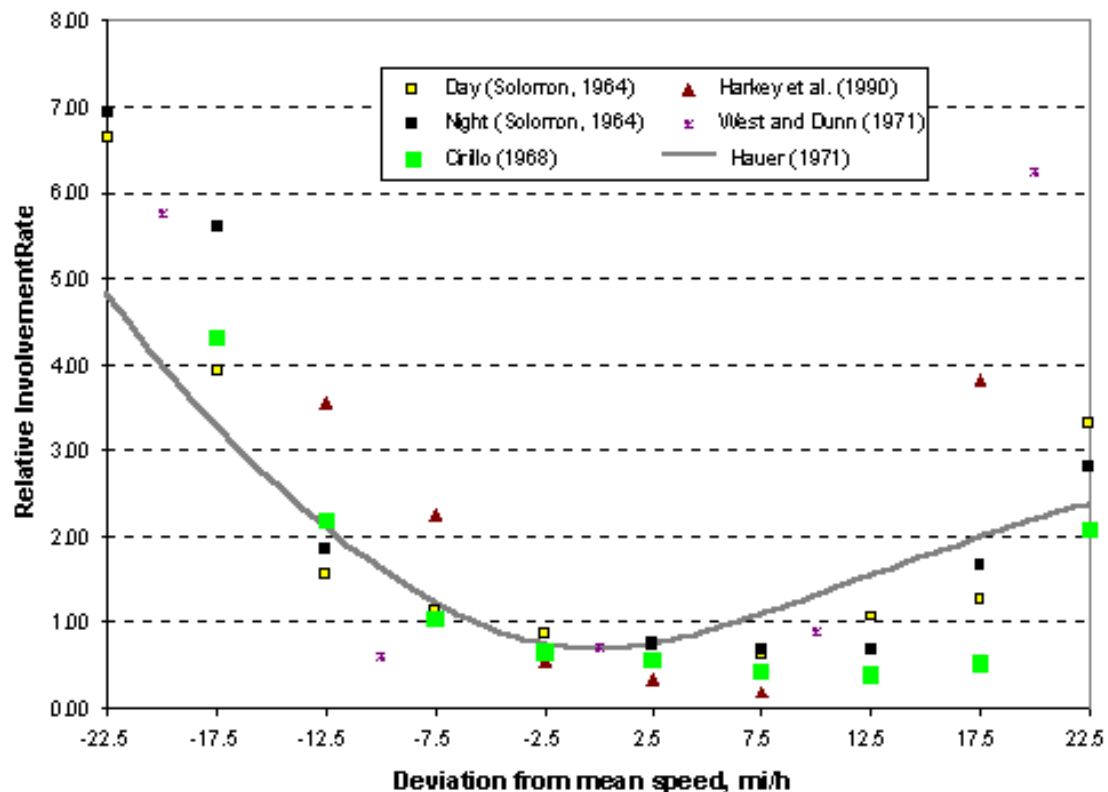


Figure 5 Crash involvement and overtaking rates relative to average rate and speed
(Source: Hauer, 1971)

Little research on speed and crashes appeared between the mid-1970s and mid-1990s. Liu et al. (1997) examined the relationship between travel speed and collision

involvement on provincial highways in Saskatchewan. The data indicate that the most prevalent source of human error contributing to collisions may be speed-related. The study of the relationship between vehicle speed and collisions therefore is fundamental for developing countermeasures to achieve compliance with speed regulations and to reduce the number of collisions. According to nine provincial-wide speed surveys and corresponding accident data from the last 26 years, traffic casualties and casualty rates on provincial highways are closely correlated to the surveyed average travel speed (Liu et al., 1997). This finding is supported by the fact that about 60 to 80% of all collisions on provincial highways are single-vehicle collisions. The relationship indicates that casualties will be reduced by about 7% for every 0.62 mph reduction in average travel speed on provincial highways (Liu et al., 1997).

Kloeden, McLean, Moore, and Ponte (1998) studied the relationship between traveling speed and the risk of crash involvement in an urban setting using computer-aided crash reconstruction techniques and case control-speed studies. They found that vehicles involved in casualty crashes were generally traveling faster than vehicles that were not involved in casualty crashes. 68% of casualty involved vehicles were exceeding 37 mph compared to 42% of those not involved. Overall, they found the risk of being involved in a fatal crash doubled for each 3.1 mph increase in speed above 37.1 mph.

Wahlberg (2000) released a report relating acceleration to accident frequency for city buses. Although Wahlberg did not find any strong relationships, he introduced several problems and remedies for this type of research. Relying on the work of Gully et al. (1995), Wahlberg studied behaviors previously correlated with accident frequency.

Behaviors such as abrupt lane changes and sharp deceleration correlated positively regardless of scientific measurement. Wahlberg used g-force to study variability of driving. If drivers driving in a more variable way have more accidents, the mean g-force would predict accident frequency. He also applied the same logic to speed. Due to the small sample and relatively large differences in exposure between bus drivers, he was not able to develop any correlations. However, the author offers several areas for consideration:

- Responsibility for crash – some drivers are in crashes with no responsibility for the crash (ex., people who are rear-ended while sitting still). Researchers should develop a method for coding responsible vs. not responsible. Although, he notes other researchers have had little success when separating crashes by fault in determining driver risk.
- Differential exposure – the amount of driving time varies greatly between drivers. There is no way to discern in previous years how many behind-the-wheel hours each driver accumulated.
- Identifying sources of bias and their impact on transferability – Using bus drivers, there is an expectation that the bus company hired the best drivers. These drivers may also have similar risk patterns.
- Correlation time-period – The length of time used for collecting crashes varies from two to three years to ten years. No one has attempted to address an optimal period of prediction.

The Relationship between Speed and the Speed Limit

In 1987, most states raised the speed limit from 55 to 65 mph on portions of their rural interstate highways. There was intense debate about the increase, and numerous evaluations were conducted afterwards. Godwin (1992) studied the effect of increasing speed limits on rural Interstate highways to 65 mph in 40 states between 1987 and 1992. Both the average speed and the 85th percentile in speeds increased on roads posted at 65 mph. Various statistical approaches for estimating the effect of these higher speeds indicate that fatalities on highways posted at 65 mph were 15 to 25 percent higher than expected in 1988.

A contradictory view was expressed by Lave and Elias (1994). They argued that these evaluations shared a common problem: they only measured the local effects of the change, not system-wide effects. In particular, the new 65 mph limit allowed the state highway patrols to shift their resources from speed enforcement on the interstates to other safety activities and other highways. The study by Elias et al. (1994) measured these changes and found raising the limit to 65 mph reduced statewide fatality rates by 3.4% to 5.1%, holding constant the effects of long-term trend, driving exposure, seat belt laws, and economic factors. However, the remoteness of the outcome variable of statewide fatality rates in relation to speed limit changes challenges their findings.

On June 1, 1987, the state of Victoria in Australia raised the speed limit on its rural and outer Melbourne freeway network to 68.3 mph from 62.1 mph. Nevertheless, in late September 1989, officials removed the higher limit and reinstated the 62.1 mph. Sliogeris (1992) studied the effect of both changes. Results showed an increase in injury accident

rate (including fatalities) per km traveled of 24.6% when the speed limit was raised in 1987 and a decrease of 19.3% when it was lowered again in 1989². This indicates a return to the former condition. Similar results were found by controlling for sub-groupings by urban/rural groups, standard of freeway, and accident severity. Sliogeris reviewed speed data and literature and it is estimated that under an established 68.3 mph regulation about 50-60% of cars would exceed 68.3 mph and 12-20% exceed 74.5 mph. A 62.1 mph speed limit is assessed as having a dampening effect on speeds with beneficial road safety results.

The National Highway Traffic Safety Administration (1992) examined the changes in fatalities that have occurred on rural Interstates for which the posted speed limit was increased from 55 mph to 65 mph. Of the 44,529 fatalities occurring in 1990, slightly more than 5% occurred on rural Interstates with a speed limit of 65 mph. Compared to 1989, nationwide rural Interstate fatalities in 1990 declined about 2%, an amount equal to the change experienced in total motor vehicle crash fatalities. This decline occurred in spite of increases in vehicle miles traveled (VMT) estimated at 2%. Urban Interstate fatalities were about 2% higher than in 1989.

TranSafety, Incorporated (1993) also studied the impact of the 65 mph speed limit on fatalities. A 3.5% reduction in fatalities resulted from the 10 mph speed limit increase. The results of the study were considered more reliable than prior literature because the study used the standardized evaluation criterion, incorporated effects on statewide fatality rate, and aggregated the data into large groups to produce more reliable estimates for fatality rates.

² Note: Assume crash count of 100. $100 \times 1.246 = 124.6$ after increase. $124.6 \times (1 - 0.193) = 100.6$

In early 1996, Texas raised the speed limit to 70 mph on highways. Crash frequency jumped significantly after the speed limit change from 55 mph (urban) or 65 mph (rural) to 70 mph. Griffin (1998) studied crash data for the period several years prior to the speed limit change and compared that history with statistical predictions for the period after the change. The study showed that crash frequency increased more than expected in 16 of those 24 scenarios, and the results illustrated a broad range of effects. For instance, the number of injury crashes on rural, multilane, undivided highways increased 9%; while the number of fatal and serious injury crashes on urban Interstate highways jumped 74%.

Speed Trends

The Insurance Institute of Highway Safety (2003) monitors travel speeds in New Mexico on a yearly basis. The monitoring activity began in 1987 and records exist for mean speed, percent over 75 mph, and percent over 80 mph (after 1993). Table 3 shows that speeds increased incrementally until the repeal of the national maximum speed limit in 1995, at which time the speed limit increased and speeds also increased sharply.

A survey of six states (IIHS, 2003) shows the majority of drivers exceeding speed limits (Table 4) at several study sites in both rural and urban areas – although the rural case is more pronounced. Along with steady increases in speeding over the last several years, vehicle engine horsepower has been steadily on the rise. IIHS researchers noted a similar trend in the car advertising encouraging motorists to “Zoom, Zoom, Zoom” (see Figure 3; Mazdausa.com, 2004). The lack of media from states discouraging speeding coupled with

the prevalence of media encouraging speeding from the auto industry appear to be heavily affecting driving behavior.

Table 3 Vehicle Speeds (mph) on New Mexico Rural Interstates
(Source: IIHS, 2003)

Speed Limit (mph)	Date	Mean Speed	Percent going faster than 75	Percent going faster than 80
65	4/1987	64	1	--
65	4/1988	66	6	--
65	4/1989	67	6	--
65	4/1990	67	7	--
65	4/1991	67	6	--
65	4/1992	68	9	--
65	4/1993	68	12	3
65	4/1994	68	8	3
65	4/1996	69	14	4
75	6/1996	72	26	5
75	6/1997	73	37	10
75	3/2003	75	55	16



Figure 6 Popular "Zoom, Zoom" Advertising Campaign from Mazda
(Source: <http://www.mazdausa.com>)

Table 4 Speeds (mph) on Rural and Urban Interstates, 2003
(Source: IIHS, 2003)

Rural Interstates				
State	Speed Limit	Mean Speed (mph)	Percentage going faster than 70	Percentage going faster than 80
Georgia	65	74	68	20
Massachusetts	65	69	44	2
Maryland	65	66	17	1
New Mexico	75	72	68	10
Colorado	75	76	84	24
California	70	74	69	19
Urban Interstates				
City, State	Speed Limit	Mean Speed (mph)	Percentage going faster than 70	Percentage going faster than 80
Atlanta, GA	55	75	78	18
Boston, MA	55	69	38	3
Washington, DC	55	67	31	2
Albuquerque, NM	65	67	25	2
Denver, CO	55	64	11	<1

Crash-Involved Driver Demographics

The following citations provide a quick summary of some of the stereotypes derived from statistical analysis of crash-involved driver demographics. Clearly, age and gender weigh heavily as the focus of most of the research. As reported by Runge (2003), Administrator of NHTSA, motor vehicle crashes are the single leading cause of death for persons under the age of 34. In terms of crashes, young drivers have a higher rate of crashes than drivers over age 24. Unsafe or illegal speed is the most frequently cited contributing factor to crashes involving young drivers.

In a Crash Outcome Data Evaluation System (CODES) study in Maine of run-off-road crashes (Finison, 1999), logistic regression indicated that injuries and fatalities from these crashes were associated with male drivers, alcohol, drivers ages 16-24, fatigue, and unsafe or illegal speed. The researchers also associated the use of seat belts with a lower risk of injury. Young drivers were 15 times more likely to be injured in crashes related to excessive speed than older drivers.

The Minnesota Department of Public Safety reported (MN DPS, 1998) that drivers ages 15-19 in Minnesota accounted for 15.8 percent of the drivers in crashes in 1998, although they accounted for 7.5 percent of the licensed drivers. Young drivers were over-represented in single-vehicle crashes and crashes involving unsafe or illegal speed or driver inexperience. In single-vehicle crashes, young drivers represented 23.5 percent of the drivers in crashes involving unsafe or illegal speed.

A number of speed-related crash studies have focused on demographic factors other than gender and age, including vehicle age and horsepower, amount of miles usually driven by driver, education and income level of driver, rural or urban driver, and many other factors.

In a synthesis on research related to speed and speed management (Stuster et al., 1998) the young driver was consistently associated with speeding and speed-related crashes. A number of the studies found an association with speeding and drivers of newer cars, high mileage drivers, male drivers, drivers with radar detectors, and drivers with low seat belt use.

In a study by LeFevre (1954), younger drivers, high mileage drivers, drivers in newer cars, faster drivers, and drivers in a hurry have more crashes. A survey of drivers' attitudes toward speed limit violations suggests directing public education toward young, educated, male, high mileage, and rural drivers (Kanellaidis et al., 1995). DeSilva (1940) found that drivers drove faster if they were out-of state drivers, drivers of newer vehicles, young drivers, and drivers on long trips. In a report by Bowie and Walz (1994), speed-related crashes were associated with head-on and single-vehicle crashes, higher injury severity, lower seat belt use, rural roads, roadway curves, nighttime crashes, male drivers, and young drivers.

According to NHTSA's Young Drivers Traffic Safety Facts 1999, of the drivers' ages 15-20 involved in fatal crashes in 1999, 23.3 percent had previous speeding convictions. In a study by Cooper (1997) there was a strong correlation between speeding violations for excessive speed (more than 24.8 mph) and speed-related crash involvement, compared with a weaker correlation between violations for moderate speeding and crashes. Elliott (2000) found that drivers with previously ticketed offenses or reported crashes were at greater risk for future offenses or crashes.

According to a 1993 NHTSA study of safety issues related specifically to younger and older drivers, younger drivers ages 15-24 and drivers age 65 and older have a higher rate of crashes than drivers ages 25-64. Among younger drivers ages 15-24, 21% of the crashes were single vehicle crashes, compared with 10% for older drivers age 65 and older. 11% of the crashes involving younger drivers entail left turning, compared with 17% for older drivers. 15% of crashes with younger drivers involved excessive speed, compared

with 5% for older drivers age 65. Failure to yield right of way was the primary error in 18% of crashes involving older drivers, compared with 9% for younger drivers. Driver inattention including falling asleep was about the same for both age groups at 5%.

Chu (1994) completed a study of elderly drivers (age over 65) in 1994. Elderly drivers are more likely to be involved in crashes than almost all drivers, except those under the age of 25 years. In the majority of crashes in which elderly drivers were involved, they were at fault for failing to yield the right-of-way, turning improperly, ignoring traffic signals, or starting improperly into traffic. Elderly drivers self-regulate by reducing daily driving exposure, avoid driving at night, avoid driving during peak hours, and avoiding driving on limited-access highways. They also drive at lower speeds, drive larger automobiles, and carry fewer passengers. Despite their efforts, the elderly still show a higher risk of crash and injury per unit of exposure than the mid-aged. Older drivers usually adjust their driving habits based on the risks they face, not on the risk they pose to others.

Driver Behavior

Driver behavior links directly with vehicle speed and safety. A Federal Highway Administration study (Harkey et al., 1990) concluded that 7 of 10 drivers exceeded the speed limit in urban areas, and compliance was worse on low-speed roads. Gabany et al. (1997) investigated the factors that predispose, enable, and reinforce drivers' speeding behavior. The research team developed a perceptual inventory and administered to a large, college-age sample. Researchers found high levels of correlation between factors. Factor analysis suggested five constructs: (a) ego-gratification; (b) risk-taking; (c) time pressures;

(d) disdain of driving; and, (e) inattention. Males agreed more strongly than females with ego-gratification items; younger subjects agreed more strongly with risk-taking and less strongly with time pressure items than older subjects; and, females agreed more strongly than males with time pressures, disdain of driving, and inattention items.

When investigating the self-enhancement bias in driver attitudes, Bathurst et al. (1998) found that drivers rate themselves better than the average driver on safety and skill perceptions. A sample of 86 New Zealand drivers participated in a survey regarding their perceptions of their own and others' speeds in two conditions, 31.5 mph and 63 mph. The results established the self-enhancement bias for speed and safety, but not skill. Between 85% and 90% of drivers claimed to drive slower than the 'average driver'. The New Zealand researchers used a new methodological technique to investigate the direction of the self-enhancement bias. The results support the Downward Comparison Theory because drivers consider other drivers negatively, rather than exaggerating their self-perception. However, psychosocial research using predictors of sensation-seeking, high aggression levels and risky life styles have not produced conclusive evidence that they are directly and significantly associated with crash involvement.

Although this research is concerned with speeding, virtually all definitions of aggressive driving include speed as the main factor of multiple factors. Therefore, it is important to review this area. There is no established definition or clear consensus as to what constitutes aggressive driving. Some researchers even question the need to separate aggressive driving from other dangerous driving behaviors. Mitzell (1997) defines aggressive driving as the intentional act of an angry or impatient motorist or passenger that

results in another motorist, passenger or pedestrian being injured or killed. Mitzell's definition is extremely narrow and the majority of researchers distinguish between aggressive driving and 'road rage'³. Road rage is generally defined as an extreme form of aggressive driving which has escalated to overt criminal behavior.

The most straightforward description of aggressive driving is simply a list of driver behaviors or errors that are commonly associated with aggressive driving. However for each item listed clear definitions are not available in the literature on aggressive driving. How close is following too closely and at what speed? How many rude gestures are necessary to constitute aggressive behavior? Driver behaviors commonly included in descriptions of aggressive driving are:

- running stop signs and red lights,
- tailgating (following too closely),
- weaving in and out of traffic,
- making erratic and unsafe lane changes,
- honking and flashing lights at vehicles perceived to be moving too slow,
- passing on the shoulder or unpaved portion of the roadway,
- unsafe or excessive speeds,
- failure to yield right-of-way,
- preventing other drivers from passing, and
- yelling or making rude gestures at other motorists or pedestrians.

³ It may be a semantic distinction. However, it is important to distinguish between aggressive driving and road rage.

De Vlieger (1997) describes three types of driving behaviors with regard to fuel consumption based on acceleration and braking. Aggressive driving is defined as ‘sudden acceleration and heavy braking’. The specific driving behaviors are defined⁴ as calm driving, 1 to 1.45 mph/s, normal driving, 1.45 to 1.90 mph/s, and aggressive driving, 1.90 to 2.45 mph/s. Although “aggressive” is not a behavioral consideration in fuel and emissions studies, similar definitions based on appropriate acceleration rates could possibly be used as surrogate measures for speeding, following too closely, improper lane change and perhaps other aggressive driving behaviors.

Stradling (2000) describes three aspects of driving. The first is technical mastery of control and maneuvering the vehicle. The second involves reading the road, developing cues to anticipate other driver’s actions and safe reactions to the unexpected. The third is described as the expressive phase where drivers develop a driving style and use driving to express their personality or attitudes. The expressive phase has been the aggressive drivers research focus to date. In exploring the expressive phase, researchers used survey tools developed by the Manchester Driver Behavior Research Group. Based on numerous large-scale national surveys in England utilizing these tools, three driver behaviors classified as lapses, errors and violations have been defined and their relevance to aggressive driving studied.

Lapses involve driver behaviors such as misreading signs and getting off at the wrong exit, forgetting where the car is parked, switching on one thing in the car when you meant to turn on another, or hitting something while the vehicle is in reverse due to not

⁴ These ranges do not include stopping and starting acceleration, but general acceleration/deceleration during normal driving.

looking. Lapses are embarrassing and inconvenient but are not usually a cause of crashes, and are most often reported by female and elderly drivers.

Errors involve driver behaviors such as failure to see a stop sign and narrowly avoiding a collision, failure to check the rear-view mirror when changing lanes, braking too hard on a slippery road or steering incorrectly in a skid, underestimating the speed of a car you are trying to pass, or failing to notice pedestrians when making a turn from a main road to a side street. Errors are failures of observation and misjudgments. Errors have no association with gender or age of driver and are not significantly associated with crashes.

Violations consist of disregarding speed limit (most often very late at night or early in the morning), running red lights, following a car too closely, passing on the right, racing other cars, or driving under the influence of drugs or alcohol. Violations are deliberate deviations from the normal safe practices necessary for driving a vehicle, or behaviors commonly known as aggressive driving. Some driver types who score high violations are male, young (aged 17-25), high mileage, high income, urban or suburban rather than rural dwellers, owners of powerful vehicles, company vehicle drivers, or people who drive as part of their work.

Stradling (2000) presents data from a recent survey of 746 English drivers that confirm previous results in England and several other European countries. Drivers who scored high on violations were more likely to have been involved in crashes in the past and more likely to be involved in crashes in the future. In addition, the high violation drivers were not only more likely involved in crashes where they were the driver that hit the other vehicle or ran off the road, but they were also more likely to be involved in passive crashes

where they were hit by another vehicle. It is interesting to note that driving with the knowledge that you may have an illegal blood alcohol level is included in the list of violations. Driving behavior involving alcohol is often not included in aggressive driving behaviors listed by other researchers.

The National Highway Traffic Safety Administration defines aggressive driving as, "when individuals commit a combination of moving traffic offenses so as to endanger other persons or property." Their list of traffic offenses commonly associated with aggressive driving includes: exceeding the posted speed limit; following too closely; changing lanes erratically or unsafely; improperly signaling lane changes; failing to obey traffic stop signs, yield signs, traffic signals, and railroad grade cross signals; and running red lights.

Typically, NHTSA does not include drinking and driving in their list of aggressive driving practices, although it is included as an unsafe/aggressive driving behavior in a recent survey of speeding and other unsafe driving practices (NHTSA, 1998). Respondents were asked about the frequency of unsafe or aggressive driving acts they had observed or committed. They were also asked which unsafe driving behaviors they felt were threatening and which they felt were dangerous. Additionally, the survey contained questions on what measures should be taken to curb unsafe or aggressive driving. The list of unsafe driving behaviors provided to respondents included tailgating, traveling at an unsafe speed, making erratic or unsafe lane changes, passing improperly, failing to yield, running red lights, racing, drinking and driving, cutting in front of a driver to make a turn, making an insulting or obscene gesture or comment, and driving through a stop sign.

The results from the 1997 NHTSA study provide a revealing snapshot of driving practices. Unsafe speed was commonly reported on all types of roads. 53% of the respondents reported that they observed unsafe speed all or most of the time when they drove on urban residential streets and 52% when they drove on rural residential streets. The reported incidence of unsafe speed on urban and rural interstates were 70 and 67 percent, respectively. On rural highways the reported incidence of unsafe speed was 55%, compared with 59% on urban highways.

NHTSA (1998) reported a number of demographic characteristics associated with unsafe or aggressive driving, using a mean composite score developed from the reported frequency of committing unsafe driving acts. Unsafe/aggressive driving practices appear to decline with age. Young drivers age 16-20 have the highest mean score at 150. In part, this can be attributed to the fact that younger drivers have less driving experience and feel there are fewer consequences for speeding and unsafe driving. Researchers found that as people age they are more inclined to view unsafe driving as dangerous. Drivers over age 65 have the lowest scores at mean of 37. The study found that men were 40% more likely to commit unsafe driving acts than women. Little correlation was found between unsafe driving and education level. The mean unsafe driving score was 78.6 for persons with less than a high school education, 67.4 for high school graduates, 78.9 for persons with some college and 80.3 for college graduates.

Finally, NHTSA (1998) found that there was a direct relationship between household income and unsafe driving acts committed. With the exception of the lowest income group, as household income increases, the number of unsafe driving acts also

increases. The unsafe driving score was 90.6 for those with 1997 household incomes less than \$5,000, 55.5 for drivers with household incomes of \$5,000-\$14,999, 67.2 for drivers with incomes of \$15,000-\$29,999, 70.2 for those with incomes of \$30,000-\$49,999, 88.1 for drivers with incomes of \$50,000-\$74,999, 91.8 for those with incomes of \$75,000-\$99,999, and 103.5 for drivers with incomes of \$100,000 or more.

In a 1995 report on youthful risk taking and driving, NHTSA attempts to use integrated theories of youthful risk taking to help explain the higher rate of motor vehicle crashes and fatalities. The vast majority of literature cited only infers an association with a particular psychosocial theory and the crashes or driving behavior observed. The studies where researchers actually conduct measurements of specific psychological traits of the driver and drew a direct relationship with driving behavior or crashes were inconclusive. In short, psychosocial theory, although valuable for descriptive purposes, cannot be used to determine cause and effect (NHTSA, 1995).

Elby (1998) cited a large number of studies that correlate sensation seeking with negative traffic safety using the Sensation Seeking Scale (SSS). A high SSS score was associated with drinking and driving, speeding, failing to use seat belts and violating traffic laws. Other areas of research did not provide great evidence of direct relationships between theory and crashes.

Regulatory Framework

The policies and legislation in Georgia affect many aspects of this study. How Georgia defines speeding and aggressive driving and dictates countermeasures to curtail them affect many of the data sources such as traffic violation conviction and crash records.

It also affects the attitudes and actions of the drivers studied. Therefore, conclusions need to be interpreted within the context of Georgia law and policy.

Speed

By state law, only state troopers (Georgia State Patrol, GSP) can issue a citation for speeding any amount over the speed limit, all other law enforcement officers may only ticket for speeds in excess of 10 mph over the speed limit (Georgia Code § 40-14-8). A few exceptions exist within this section, they include speeding in operational school zones, speeding in historic districts, and speeding in properly marked residential areas with posted speeds at or below 30 mph.

Individual jurisdictions or precincts set policy that modifies that restriction further based on a number of considerations including their perceived ability to get a conviction under varying circumstances (sometimes set at 20 mph over the speed limit). There are many legal limitations to the use of radar including the police car must be visible for at least 500 feet (Georgia Code § 40-14-7); radar cannot be used on a road that has a slope greater than seven percent (Georgia Code § 40-14-9); and counties, municipalities, colleges and universities must post warning signs along the roadways at their boundaries warning drivers that such devices are being used (Georgia Code § 40-14-6). Without radar or laser detection the officer must tail the vehicle to determine speed, which is difficult to do and less likely to stand up in court.

Convictions are issued by a point system (Georgia Code § 40-5-57). Drivers who exceed 15 points in 24 months receive a one-year suspension. The point system for exceeding the speed limit is 2 points for 15-18 mph over the speed limit, 3 points for 19-23

mph over the speed limit, 4 points for 24-33 mph over the speed limit, 6 points for 34 mph or more over the speed limit, and 0 points for driving too fast for conditions. Table 1 provides combined fines and points penalties for speeding at various amounts over the posted speed limit. Not only do the points accumulate toward the suspension of the drivers' license, but are also included in the determination of insurance pricing. Points accumulated toward the license can increase insurance payments significantly.

Aggressive Driving

In the 2001 legislative session, legislators enacted the offense of aggressive driving to the traffic laws in Georgia. The Governor signed House Bill 671 into law in 2001 producing significant changes in speeding policy in Georgia (Georgia Code § 40-5-142, 40-5-57, 40-6-123, 40-6-397, and 40-6-49). The law establishes aggressive driving as a separate 6 point code violation (Georgia Code § 40-5-57). Further, aggressive driving is added to the definition of 'serious traffic violations' (Georgia Code § 40-5-142).

The offense of aggressive driving is defined (Georgia Code § 40-6-397) as, "operation of a commercial vehicle at a speed in excess of 75 miles per hour or any motor vehicle other than a commercial vehicle at a speed in excess of 85 miles per hour; or while exceeding the legal speed limit by more than five miles per hour while operating a commercial motor vehicle or more than ten miles per hour while operating any other motor vehicle, commits one or more of the following violations:

- Failure to obey traffic control devices
- Overtaking and passing another vehicle on the right by driving off the pavement or main traveled portion of the roadway

- Unsafe lane change
- Following a vehicle too closely
- Failure to yield the right-of-way
- And the person's driving is an immediate hazard to another person or vehicle.”

A person convicted of aggressive driving is considered guilty of a misdemeanor of a high and aggravated nature.

A person convicted of a violation of section 40-6-397 of the Georgia Code receives 6 points against their license and must attend and successfully complete a driver improvement course to improve the safety and habits of drivers. The court must forward the abstract of conviction to the Department of Public Safety (DPS) and has the authority to order the department to suspend the person's driving privilege for 30 days. If a person who is convicted of a violation of this Code section has been previously convicted of a violation of this Code section within a period of 24 months (in addition to any other penalty prescribed by law), the court forwards the abstract of conviction to the DPS. On receipt of the abstract of conviction, the department will revoke the driving privilege of the person for one year.

This changes speed laws, previously only Georgia State Patrol officers could cite drivers for any speed over the speed limit, now any police officer can cite for 5 mph over the speed limit if it occurs as part of aggressive driving. Unfortunately, the police officers do not tend to be using the new legislation to its potential. In 2003, only 336 convictions were posted for the offense in Georgia.

Prior changes in the speed policy were limited to drivers under age 21. The Teenage and Adult Driver Responsibility Act (TADRA) went into effect on July 1, 1997 and changed the speed laws for drivers under age 21. The greatest decline in motor vehicle crashes involving drivers ages 16-17 was in speed-related fatal crashes. The fatal crash rate per 100,000 licensed drivers' ages 16-17 declined 44.5 percent in the 18 months after TADRA enactment, compared with the 18 months before the law was in effect (DMVS, 2000). Since enactment of the Teenage and Adult Driver Responsibility Act (TADRA) on July 1, 1997, drivers age 18 have the highest fatality rate in Georgia.

Driver Records

The Georgia Driver (History) File contains driver name, license number, gender, age, license type and status, renewal information, and traffic convictions received from the state's court system. The Driver History File does not contain crash history unless a citation resulted from the crash, and was subsequently convicted by the court. Traffic convictions from another state may or may not be included. Georgia does not have a Citation File, only a Conviction File. The traffic citation conviction file may be incomplete, because there is no comprehensive statewide sequential citation document numbering system, although each document is numbered. No accounting system exists for all citations. The citation record does not contain information on when, where, or how the citation occurred. Speed violation convictions for violations less than 15 mph over the posted speed limit are not recorded in the Driver File. The GBI maintains a separate file in the Uniform Crime Reporting Unit for arrests and convictions for alcohol or drug impaired driving.

Ideally, the Driver History File would contain a complete driver history. This would include all crashes, not just those that resulted in a point violation, and also crashes and violations from other states. Obviously in order to have a complete driver history file a complete/citation conviction file is needed. All citations and convictions would be included along with information on when, where and how citation occurred. The driver history, crash, and citation file would be linked and accessible.

The following section was taken from the State of Georgia Traffic Records Assessment. It explains the two types of files maintained on Georgia drivers, including the Georgia Driver file and the Georgia Citation/Conviction File.

Georgia's Driver File

The Driver File is managed by the Department of Public Safety (DPS) and resides on the Department of Administrative Services' (DOAS) mainframe computer. A driver record is established in the Driver File at the time of initial driver license application. The file contains renewal information and traffic convictions received from the State's court system. By Georgia statute, the Driver File does not contain crash histories unless a crash has resulted in a traffic conviction for that driver. This situation has implications for the use of the driver records in the identification of problem drivers.

Court systems from some larger Georgia jurisdictions electronically submit court conviction data to the DPS. This accounts for about 140,000 records annually. The remainder of conviction data (approximately 500,000) are submitted via hardcopy. Georgia statute requires a court to provide conviction notice to the Driver File within 10 days, but this rule is not strictly adhered to. Logically the key entry of hardcopy conviction

data in the Driver File is prioritized according to the severity of the offense. Convictions requiring mandatory suspension (such as DUI) receive first priority. Lower priority convictions, such as stop sign violations, could take as long as six months from the time of citation issuance until the conviction record is entered on the Driver File. Courts have on-line access to the Driver File.

Unlike more than 40 other states, Georgia does not participate in the Driver License Compact (DLC). However, Georgia does participate in the Non-Resident Violator Compact and went on-line to the Problem Driver Pointer System (PDFS) on April 2, 1995. Georgia driver license records are confidential and are not available to the general public. Anyone wishing to access the file must show a compelling reason for receiving access to the record.

The prior driving histories from other states are not added to the individual's driver history. Persons with poor driving records in adjoining states have established Georgia residency to obtain a "clean" driving record, adding to the difficulty in tracking accurate driver histories. In response, the State of Georgia strengthened residency requirements.

Problem drivers are identified with a point system. Drivers who exceed 15 points in 24 months receive a one-year suspension. Rather surprisingly, speed violation convictions for violations less than 15 mph over the posted speed limit are not recorded in the Driver File. Convictions on speed violations of more than 15 mph over the posted speed limit result in two points on the driver record; convictions for violations over 30 mph over the posted speed limit result in six points. Three or more DUI convictions in five years result in a five year license suspension.

Georgia's Citation/Conviction File

There is no statewide Citation/Conviction File in Georgia. Some local law enforcement agencies may maintain Citation Files. The DPS is responsible for and has developed a uniform traffic citation that is mandatory for all law enforcement agencies in the State. Many of the local agencies print their own citation forms which contain the elements and format prescribed for the uniform citation.

There is no comprehensive statewide sequential citation document numbering system, although each document is numbered. No accounting system exists for all citations. Many local agencies have developed a local citation accounting system.

There is also no statewide uniform citation tracking system. Each court system manages its own citation tracking. Because there is no sequential numbering system and each court has its own system of accountability. Thus, it would be very difficult to conduct an audit of the citation activity in the State.

Law enforcement agencies deliver hardcopies of citations to the appropriate court. After disposition by either volunteer uncontested payment of a fine, or conviction, the appropriate disposition is forwarded either electronically or via hardcopy to DPS for inclusion onto the driver's history record file. Routinely there is no citation disposition or summary information sent back to the local agencies for the citations they write.

None of the elements of the citations are entered into a statewide database. Therefore no citation data are available for analysis of problem evaluation. No reports indicating basic criteria (such as date, times, and location) are available for comparison to

accident criteria and individual officer performance. The Georgia State Patrol (GSP) currently has an officer activity reporting process that is being incorporated into a new departmental information management system.

Because there is no database of citation/convictions, no summary inquiries are available to count types of citations and convictions by location, violation categories, or ages/sex of drivers. There can also be no problem identification and evaluation to determine the level of enforcement activity relative to a roadway location, types of citations, and vehicles involved. Currently, it would be very difficult to determine whether citations are being processed, adjudicated, and dispositions recorded as prescribed by law and policy.

In 1991 the State instituted the Courts Automation Commission. One of the early activities of the Commission was to develop a court PC-based information system called the Traffic Court Management System (TCMS). All state and municipal prosecutors and courts have access to the driver history files for prosecution purposes. The access is electronic and available to all courts via Georgia On-line (GO) Network. Traffic misdemeanor records are also contained in the criminal records of the Georgia Crime Information Center (GCIC). This includes conviction records for DUI offenders. Overall, the data are improving.

Summary of Previous Research

There are four general methods that have been identified in the literature and used to study the relationship between driver speed and crashes. Most of the previous studies have focused primarily on rural areas. The methods and their associated limitations are:

- Comparisons of speeds and crashes before and after a speed limit change
 - Limited to certain portions of speed distribution (i.e., change from 55 mph to 65 mph)
 - Limited information relating to other environmental aspects of the site which may affect speeds
 - Uncertain as to whether relationship holds for individual crashes
- Comparison of estimated pre-crash speed of an individual vehicle to speeds of case-control vehicles at same location, day of week, and time of day post-crash
 - Limited accuracy in determining pre-crash speeds (most based on police reports or estimated using crash reconstruction methods)
 - Uncertainty whether case-control speed distribution is similar to that at the actual time of the crash
 - Expensive and labor intensive
- Comparison of individual driver speed at a specific place in time with that individuals crash record
 - Limited to a small number of sites, which may or may not be representative of the drivers general exposure to posted speed limit and functional class
 - Assumes that drivers speed at observation location is indicative of speeds on other occasions
 - Assumes a relationship between speed at the observation site and previous pre-crash speeds
 - Fatal crashes, which are synonymous with speeding, are not represented

- Comparison of drivometer or instrumented vehicle speed behavior with crash history
 - Previous drivometer research did not allow relation of speed to speed limit or other spatially available environmental information
 - Assumes that drivers behave the same in research vehicle as they do in their own vehicles
 - Limited to a controlled route
 - Observation period is short, and observation bias may exist (directly related to conspicuity of in-vehicle equipment)

Each of these methods have associated limitations and shortcomings which have led to questioning of the results. In general, trends among all of the previous research studies indicate that increases in speed are associated with increased crash risk and severity.

In terms of the driver behavior component, young male drivers, high-income drivers, drivers of newer vehicles, high exposure drivers, and drivers in congested areas are more likely to violate the speed limit. Given that the development of behavior is directly associated with the consequences, or lack thereof, limited feedback during the driver learning process, conservative roadway design features, limited enforcement, and lenient laws and penalties can reinforce driver speeding behaviors.

Speeding behavior tends to decrease as drivers' age increases. Young drivers have much higher speeding conviction rates and speeding-related crash rates than drivers of other age groups. Therefore, behavior modification treatments directed at young learner

drivers have the potential to permeate the system over time reducing the effects of speeding throughout the drivers' lifetime.

Nonetheless, even older drivers speed on occasions, and it is the quantification of this continuous pattern of behavior that this dissertation is hoping to capture. In all of the previous studies of speeding behavior and crash involvement, speeding behavior is only quantified at a small number of sites, which may or may not be representative of the drivers general exposure to posted speed limit and functional class. Additionally, there is an assumption that drivers speed at observation location is indicative of speeds on other occasions. A study of the relationship between driver speeding behavior and crash involvement requires knowledge of the speeding behavior patterns of the driver. Knowing that the driver was speeding prior to a crash is valuable information; however, knowing whether or not this is common behavior is even more telling. Perhaps the occasional speeder does not know how to handle speed on curves, and will make more mistakes than the driver who perpetually speeds. Perhaps it is type of road on which one chooses to speed that is more important to crash causation while speeding. This dissertation seeks to develop methods to quantify driver speeding behavior from continuous data recording.

Chapter Four

DATA COLLECTION

The behavioral-based study of driver speeding requires data associating where, when, and by how much drivers are speeding above the posted speed limit. Advancements in technology have occurred over the last four to five decades with direct implications for travel behavior research. The development of computers, digital media, electronic and digital sensors, wireless communications, and global positioning systems are examples of these technologies. Concurrent with these advancements is the evolution of increasingly complex vehicle mechanical systems. To maintain these systems, engineers have developed onboard diagnostics, to help mechanics discern problems with sensors and systems. The ability to store and retrieve data from these electronic systems has led to the development of technologies to support event data recording. The research described in this dissertation utilizes data from in-vehicle instrumentation including location, speed, and engine parameters to develop driver speeding profiles.

The Commute Atlanta program, funded by the Federal Highway Administration (FHWA) Office of Value Pricing Programs and the Georgia Department of Transportation, provided the resources to develop and deploy the in-vehicle instrumentation and participant recruitment. The Commute Atlanta Program is designed to directly evaluates consumer response to converting fixed automotive insurance costs into variable driving costs, and begins the collection actuarial data necessary to forge the links between driver activity, on-road behavior, and crash risk. Using data from the baseline year, the necessary framework and analytical methods were developed for analyzing driving behaviors.

The Commute Atlanta program provided the majority of the data used for the present analysis. These data were supplemented by obtaining additional resources from the Georgia Department of Motor Vehicle Safety (DMVS) and Georgia Department of Transportation (GDOT). The additional sources include state crash databases as well as the roadway map databases and related roadway characteristics (i.e., posted speed limits and roadway functional class). By merging the roadway information with data collected from the in-vehicle instrumentation, it is possible to calculate the difference between the observed driver speed and the posted speed limit. Further, by using the household demographic information collected in the household survey, it is possible to identify research participants involved in crashes by querying the crash databases for name, birth year, vehicle identification number, license plate, county of registration, make, model, and year of the vehicle.

A thorough speeding profile was developed by combining household statistics, driver and vehicle characteristics, second-by-second vehicle operating information, crash history, and roadway data (see Figure 7). The following sections describe the data sources and collection of data in detail. A brief overview of the Commute Atlanta program provides details necessary to understand the recruitment and instrumentation choices, as well as the participants understanding of the project parameters.

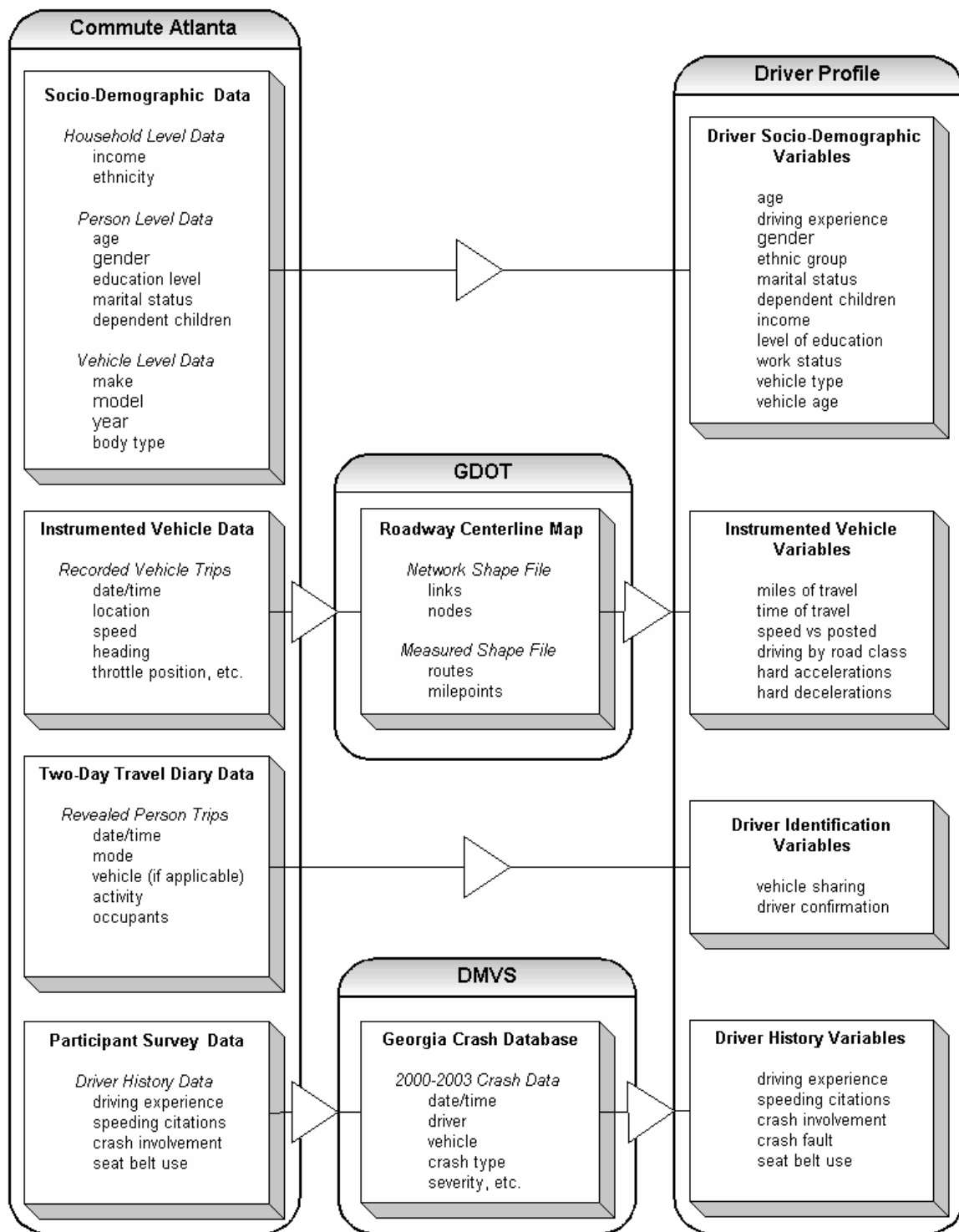


Figure 7 Data Sources to Driver Profile Information

Commute Atlanta Overview

The main objective of the multi-year Commute Atlanta program is to assess the effects of converting fixed automotive insurance costs into variable driving costs. The overarching research hypothesis is that given a per-mile pricing system, participants will modify their driving patterns in an effort to reduce their total mileage, pocketing the savings. To establish baseline travel patterns, the research team is currently monitoring vehicle trip making undertaken by the Commute Atlanta pool of household participants for one year with no pricing treatments. The research team installed 487 GT Trip Data Collectors in the vehicles of 268 participating households to collect second-by-second vehicle activity data (vehicle speed, acceleration, position, and engine operating parameters).

The Commute Atlanta project includes the parallel collection of instrumented vehicle data, household socio-demographic surveys, two-day travel diaries, and employer commute options surveys. Assessment of pricing response requires that the researchers collect information about the socioeconomic factors that may affect consumer choice. In the second year of the study, insurance rates for the 268 household study participants will be implemented on a per-mile basis, such that if they continue their pre-existing driving patterns, their annual insurance premiums will remain unchanged. Participants that reduce their household miles of travel will receive insurance rebates in accordance with their mileage-based rate schedule.

At the beginning of Year 2, the participating 268 households will report their semi-annual insurance premiums to the research team. Copies of the premium statement

will serve as sufficient evidence of this premium. For each household, the research team will calculate a mileage-based insurance rate by dividing their annual premium by last year's accrued vehicle miles of travel (monitored in Year 1 using the onboard computer system). Every month, participants will receive a statement from the research team that compares the equipment-reported VMT with their expected monthly travel. Households that drive less, carpool, shift to transit, or otherwise reduce their travel demand, will receive a quarterly incentive check equal to the quarterly reduction in VMT times their mileage-based insurance rate.

During the third year of the study, the participants will experience a "risk-adjusted" premium rate schedule. Insurance premiums in the third year will incorporate risk factors such as time of day, congestion levels, high speed, and hard acceleration into the mileage exposure-based rates. By encouraging drivers to reduce aggressive driving, thereby reducing the number of crash events, researchers expect reductions in congestion delay associated with these incidents. During the third year of the study, the participants will have the opportunity to opt into the enhanced "risk-adjusted" premium rate schedule. The premium pricing structure in Year 3 will be designed to discourage aggressive driving behavior. For example, cents/mile premiums may increase significantly for vehicle activity in excess of 10 mph above the posted speed limit, and for repeated accelerations/decelerations over 6 mph/s. As in Year 2, participants will also receive a monthly statement from the research team that compares the equipment-reported VMT and summarizes their driving activity. Households that reduce their exposure to risk (as defined by the rate structure) will receive a quarterly incentive check, calculated using their quarterly activity data.

As mentioned previously, the majority of the data acquisition occurs through the Commute Atlanta Program. The participants, recruitment methods, and equipment are all functions of the Commute Atlanta program objectives. The Commute Atlanta research program spans three years and includes multiple data collection efforts. Year 1 is the baseline year and includes no treatments. Due to seasonal variations in travel, researchers determined that a one-year baseline was necessary to develop appropriate relationships between pricing treatments and changes in travel behavior in future years. The implementation of pricing programs will begin in year two (starting January 2005) and will continue into year three. This dissertation uses only a portion of data from the year one baseline data collection period. At the time of this report, households recruited into the project in the earliest phase are nearing completion of the year-one baseline data collection. The research team recruited and installed data collection equipment in the personal vehicles of participating households over a 6-month period; therefore, baseline data collection will continue for some households through December 2004.

There are seven main components involved in the Commute Atlanta data collection effort, a brief description of each follows:

- Recruitment – Recruitment includes the sample selection, advance mailings, the actual recruitment call, and explanation of the research program to potential participants.
- Household socio-demographic survey – Collection of standard household, person, and vehicle socio-demographic information via computer-assisted telephone interview (household address, household income, number of persons in household,

employment status, education level, number of vehicles, class, makes, models, and model years of vehicles, etc.).

- Consent and installation – According to the protocols established for receipt of the study's Certificate of Confidentiality (from the National Institutes of Health), each household member of driving age signs a consent statement to participate in the study prior to installation of in-vehicle equipment. Certified and insured installers travel to the participants home or work location and install the in-vehicle trip data collection equipment in the participants' vehicle.
- In-vehicle data collection – After installation, automated collection of second-by-second trip information (e.g., date, time, location, speed, heading, and other engine parameters) commences, with weekly downloads via cellular connection within the in-vehicle equipment package.
- Annual two-day travel diary surveys – Each household member maintains a standard two-day diary of their travel, recording the times and places visited and the activities undertaken. Travel diary data are retrieved through a computer-assisted telephone interview (CATI) by a third party contractor.
- Annual employer surveys – Researchers survey employers of the participants to assess the commute incentives offered by the employer (i.e. transit passes, carpooling, telecommuting, and parking). The household surveys include parallel questions for the participants. This research component is necessary to ensure that noted changes in travel behavior result from the incentives implemented and not because an employer unexpectedly begins charging for parking or providing subsidized transit passes.

- Participant Survey – At the end of year one, each participating household received a supplemental survey. The survey served to verify household, vehicle, and personal information, and obtain information for changes in household structure and vehicle ownership. The survey included a section for each person of driving age in the household. Along with verifying the age, education level, and work status among other items, the drivers were asked to self-report their driver history including crashes and speeding offenses and provide minimal attitudinal data on speeding. These self-reported data will be compared with the information retrieved from the DMVS to verify the accuracy of the crash data.

Review for Use of Human Subjects in Research

For all research involving the use of human subjects, such as the Commute Atlanta program, researchers must submit research protocols to the Internal Review Board (IRB) for review. The IRB protects subjects from potential risks of participating in the research. Federal law and regulations apply to the collection and dissemination of the data where human subjects are involved. In implementing the Commute Atlanta Study, researchers were required to develop a detailed research plan, specifically addressing the protection of participant interests. The IRB reviews every document that researchers submit to participants, including letters, brochures, and surveys.

The main document required by IRB is the consent form. The consent form describes the project in sufficient detail and provides the participant with known risks associated with the research. The document also includes contact information for the principal investigator and IRB representative in case there are negative repercussions

associated with the research, the participant will know whom to contact. Some surveys may only require verbal consent from the participant; however, projects that acquire substantial personal information or where instrumentation is used require written content. Prior to participating in the Commute Atlanta research program, all participants received a consent form. In most cases, participant signed the form in the presence of the installer, thereby using the installer as the witness. Researchers instructed the installers to forego the installations without a signed consent form. In the scenario where a minor (under age 18) entered the study, both the minor and parent were required to sign assent and parental permission forms. A copy of the consent form can be found in Appendix B.

The IRB ensures that researchers implement best practices for protection of these private data, including data encryption, single point data warehousing, restricted access to raw data, data distillation prior to use in research efforts, and destruction of data when studies are complete. Protecting the privacy of Commute Atlanta participants is a cornerstone of the ongoing research efforts. Disclosure of personal vehicle activity data (location at a specific date and time, speed relative to speed limit, actions taken immediately prior to a vehicle crash, etc.) could potentially harm participants if used against them in legal proceedings. Commute Atlanta researchers obtained a National Institutes of Health Certificate of Confidentiality to provide an additional level of legal protection to participants to minimize risk that any of their vehicle data could be used against them in court (see Appendix B).

Researchers must process data collected in the current instrumented vehicle project before they can be disseminated outside of the research laboratory. All details that could be

used to link specific travel activity back to an individual, household, or their vehicle must be removed from the data set prior to dissemination. Hence, data summaries are readily disseminated, but individual driving traces with position information linking back to a household location may not be shared.

While the researchers have obtained a NIH Certificate of Confidentiality to protect research participants, the risks of participating in and conducting the research are real. Extremely tight controls are kept on all data containing information from which participants may be identified. Researchers have set up secure areas with an intranet of data processing and archival machines. Computers with trip or participant-related data are not allowed on the Internet network. For most purposes, researchers do not need personal name and address information to complete analyses and subject IDs are sufficient. Therefore, these data are kept on CD-Rom and accessed only when necessary. Precautions used in this research are similar to those used by researchers conducting experiments in medicine and psychology.

Recruitment

Originally, the research plan called for two recruitment and installation phases – the pilot phase, and full recruitment. However, the full recruitment did not result in completion of households in several recruitment cell strata, so the research team added a subsequent recruitment phase (Phase II). Figure 8 shows the timeline for all three phases along with the timing of the individual research components. The pilot phase consisted of testing recruitment scripts and key study concepts on a small sample of participants. This same group also served as the plant group for testing equipment installation and final field-

testing of equipment. The pilot phase sought to determine: 1) participants understanding of the study based on the recruitment scrip; 2) factors that attract them to the study; 3) factors that positively and negatively affect their active participation; 4) willingness to have vehicles instrumented; and 5) logistics for setting installation appointments and completing installations. The pilot phase resulted in the addition of information regarding the project description; the transfer of responsibility for initial appointment scheduling to the recruitment firm; and additional completion checks for household information, especially alternative telephone contact information. Researchers completed the pilot phase in June 2003. Phase I recruitment began in July 2003, and Phase II began in November 2003.

Phase	Component	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04
Pilot	Recruitment	■										
	Installation	■	■									
	Summer Diary	■	■									
	Spring Diary											■
Phase I	Recruitment			■								
	Installation			■	■	■	■	■				
	Summer Diary			■	■							
	Spring Diary											■
Phase 2	Recruitment							■				
	Installation							■	■	■		
	Spring Diary											■

Figure 8 Phasing and Implementation Schedule

Sample Selection

The research team developed the sampling framework (household and vehicle recruitment) to specifically accommodate hypothesis testing within the insurance-based research goals described above for the Commute Atlanta Program. Prior to sample selection, the research team established income, household size, and vehicle ownership groupings that reflect the distribution of households in the Atlanta region. The selection of

sampling strata in the Commute Atlanta Study relied upon the 2001 Atlanta Travel Survey (SMARTRAQ) considering the following rationale.

From the outset, researchers determined the need for random stratified sampling based upon household size, income, and auto ownership. There was consideration of representative spatial distribution during sample recruitment, but only as a check during the recruitment process and not as a part of the overall sampling control. Observation of transit diversion was of interest to the program; however, because researchers could not focus the study on a single corridor, there was no option to bring in availability of transit as a household sampling variable. Constrained by budget, researchers could only sample across a few strata. Hardware and recruitment costs, diary sampling, etc., limited the program to a maximum of 500 vehicles.

As a starting point, researchers used the previous 8,000 household Strategies for Metropolitan Atlanta Transportation and Air Quality (SMARTRAQ) survey to establish the sampling cross-classification matrices (the SMARTRAQ matrix will ultimately be used in comparative analyses as well, to examine the potential impacts of variable pricing throughout the region). Income bins were established in \$10,000 increments (\$0-\$100+), household size bins from 1-7+ persons/household, and auto ownership bins from 0-4+ vehicles/household. Researchers immediately eliminated zero-vehicle households, and high-income (greater than \$100,000 annual income) single-vehicle households, given that the study goals were to examine the effects of pricing on travel modification. Zero vehicle households did not provide opportunities for insurance pricing, and high-income single vehicle households would likely require pricing above what would be reasonably

acceptable before modification would take place. The matrix proved useful in developing sample subsets. Researchers established expected values for vehicles in each final stratum and estimated the recruitment call burden to complete some combined strata that represent a smaller percentage of total households. Researchers included extra households in each stratum to account for attrition during the experiment.

For the purposes of the Commute Atlanta Program, researchers wanted to account for auto availability in the household to monitor changes in commute patterns as well as the overall changes. Shared cars leave fewer transportation options and are important in the sample. However, households with more vehicles than drivers were not likely to be important, since shifts across vehicles were not expected. Income is also a potential factor in travel change. Given the limited budget, the research team aggregated the highest income groups.

Iterating between developing a selection criteria and evaluating the number of households and vehicles (based upon vehicle/household data) that would end up being included in the study (plus a check to make sure recruitment call burdens would not be too great), the research team examined quite a number of sampling strata. The final random stratification are shown in Table 5.

Given previous research on speeding behavior, young, male, drivers of newer cars, and rural drivers are pre-disposed to speeding behavior – the most prominent of these factors are age and gender. Therefore, a random sample with representation by age and gender would probably provide a good basis from which to draw statistical conclusions on

Table 5 Sampling Plan and Recruitment Totals⁵

Sampling Group	Annual Income	HH Size	# Vehicles	Population %	Target	Recruited Phase I	Recruited Phase II	Total Recruited
0	Any	Any	0	7.4	0	0	0	0
1	<30k	Any	1+	18.4	40	15	5	20
2	30-75k	1	1+	11.3	40	21	13	34
3	30-75k	2+	1	6.8	40	9	9	18
4	30-75k	2	2+	10.6	40	23	15	38
5	30-75k	3+	2+	13.9	40	19	15	34
6	75+	1	1+	2.8	0	5	0	5
7	75-100k	2+	1+	12.1	40	39	2	41
8	>100k	2+	1+	16.8	40	73	0	73
99	Unknown	Any	Any	n/a	0	3	2	5
				100	280	207	61	268

speeding behavior. However, other factors including vehicle age and urban/rural area have also been shown to correlate with speeding behavior. In which case, a stratified random sample across age, gender, income (correlation between income and vehicle ownership), and geographical area may provide additional benefits. Although the sample selection designed for Commute Atlanta is not optimal for studying speeding behavior, the sample should be sufficient for initially quantifying differences in speeding behavior among groups of individuals, as well as studying the speeding behaviors of individuals participating in the research.

Instrumented vehicle research programs are quite expensive and therefore are few in number. As such, researchers must make the most of the opportunities provided by

⁵ Notes:

- Annual income is the reported combined gross household income
- # Vehicles indicates the number of vehicles owned by members of the household, including leased and business-owned vehicles
- Population percent reflects the percentage of Metropolitan Atlanta households that falls into each strata
- Target reflects the targeted number of households to be met by the recruitment subcontractor
- Recruited indicates the actual number of households recruited by the subcontractor

funded programs. Where sample sizes are insufficient in some cells, weighting techniques provide possibilities to extrapolate the data to match the population. It is where there is no, or very limited, representation by a group that causes greater problems and limits the application of results to the population. There may, therefore, be limitations of this research in terms of application to low income drivers. The presence of shared vehicles in these households are more likely, as reported later shared vehicles are filtered from this research. The lack of zero vehicle households does not affect this study, since these portions of the population would not participate in speeding.

Survey Methodology

The recruitment firm used a standard phone list for the Atlanta region, randomly selected households to receive advance letters, and then subsequently called households to recruit participants. The participants were told that their participation would help to identify congestion location, and obtain more detailed information on commuting patterns. During each call, the recruitment firm first determined the household target sampling strata. For this study, researchers targeted a minimum of 35-40 households per recruitment strata. In most cases, surveyors obtained household socio-demographic information during the recruitment call. This telephone call also served to set the schedule for installation of the in-vehicle equipment. During Phase I, households were also scheduled for the 2003 Summer Travel Diary Survey that immediately followed recruitment. Phase II households were recruited and in-vehicle equipment installed in their personal vehicles up to five months in advance of the 2004 Spring Travel Diary Survey. All Phase I households were re-recruited for the 2004 Spring Travel Diary Survey. As shown in Figure 8, the length of time between recruitment and installation spanned up to four months.

Figure 9 shows the flow of the recruitment through all stages including installation. The starting point of the flow diagram is the uppermost block, entitled select sample. The initial process loop includes geocoding household locations, mailing advance letters, and placing the recruitment call. Following recruitment, travel diary days and equipment installations are scheduled. Each of these also defines a loop. The convergence of the installation and travel diary retrieval processes occurs with the completion monitoring process. While the travel diary process can progress without issue, the installation may not necessarily be completed. Therefore, the monitoring process was not only critical to the recruitment process, but also the most difficult in terms of logistics. The following sections describe the major steps associated with the recruitment effort.

Verification Call

Due to the large time gap between the recruitment interview and conduct of the travel diary phase of the study, the recruitment firm recommended a verification call to each participating household be completed prior to the start of 2004 Spring Travel Diary. This verification call served five key purposes:

- Raising the likelihood that respondents would follow all the instructions and complete the survey materials in a timely manner;
- Providing an opportunity to further reinforce legitimacy and to answer any participant questions;
- Allowing for a data item completion or correction process (eg., changes in households status like income, household size may be verified and adjusted);
- Serving to measure nonparticipating households; and
- Assigning travel day pairs.

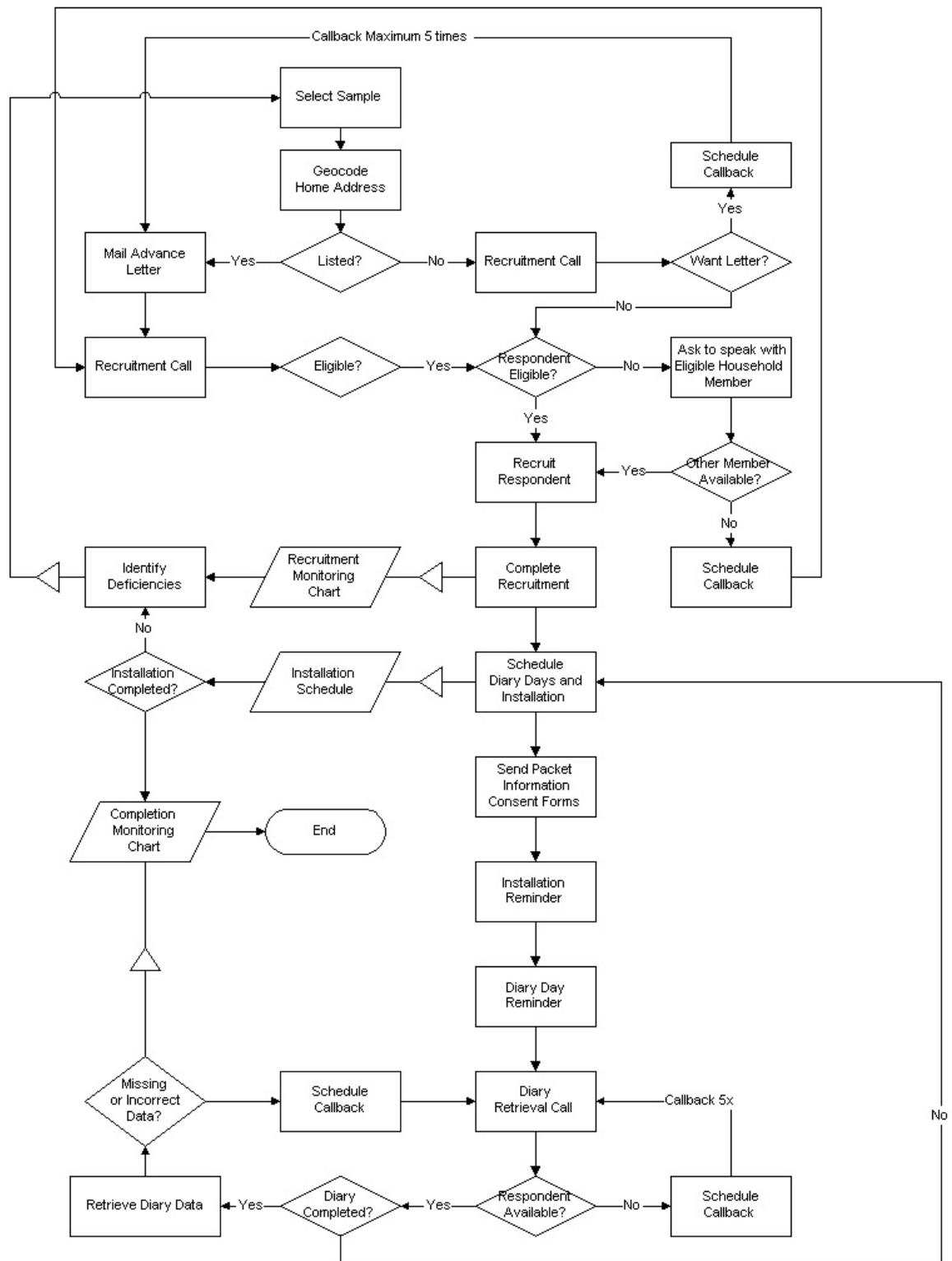


Figure 9 Recruitment and Installation Process Diagram

Mailing of Survey Packet

The diary pack that is sent to recruited households plays a critical role in the overall success (response rates) and quality of the survey. The recruitment firm uses this diary mailing to both encourage participation and improve the quality of the information reported. As a result, the diary mailing included a variety of tools and resources that made the task of participation in the study clear and simple. Within one day of the verification call, a survey packet was mailed to each recruited household. For Phase I with an immediate travel diary survey, packages included all materials and a secondary diary was mailed immediately after the verification call for the spring diary days. For Phase II, two packages were mailed – one at initial recruitment with the cover letter, brochure, and frequently asked questions document; and the second prior to the 2004 Spring Travel Diary immediately following the verification call. The packets contained:

- A cover letter, with a custom-worded “thank-you” to the respondent household,
- A tri-fold brochure, which provided information about the steps involved in the program and benefits of participation as well as additional information about the survey, including a toll-free “800” number,
- A refrigerator magnet with Commute Atlanta contact information,
- A consent form describing the program in detail and any risks associated with participation (required by Georgia Tech Institutional Review Board for all projects using human subjects),
- A sheet that reminded households of the assigned travel days AND the callback appointment time for diary collection,

- A sample “completed” diary excerpt that also provided tips on how to complete diaries most efficiently, and
- A paper travel diary for each member of the household.

A copy of the all participant materials, with the exception of the consent form located in Appendix C.

One diary was completed for each household member. To personalize the diaries, the recruitment firm labeled each diary separate with the name of each household member. The labels on the diary also contained serialized codes that allowed the diary to be linked to a participating household within the recruitment system.

Reminder Call

The recruitment firm placed a reminder call to each household up to two days before the household’s assigned travel days. Reminder calls were made as close to the assigned travel day as possible. If the reminder call was made too far in advance of the travel day, the effect of the call was significantly reduced.

Retrieval of Travel Data

The recruitment firm scheduled retrieval appointment calls for the day following the two consecutive days on which the participant recorded travel to retrieve the diary information. During this call, surveyors collected trip information from each household member. Recruiters used multiple call-backs in an attempt to collect diary information from each household member directly. Travel diary information from one household member could be provided by another, then coded as “proxy” in the data set. A

household was considered “completed” when demographic, travel, and activity data had been collected from all adult household members eligible to participate in the survey.

Recruitment and Installation Rates

After the initial round of sampling, the researchers determined that the sample make-up was skewed to higher income households. This occurrence was thought to be related to the theft tracking capabilities of the device, as well as the general technology and congestion focus of the program objectives. The recruitment of higher income households was much more successful than is normally the case in standard travel diary studies. Surveyors targeted the final round of recruitment toward obtaining lower income households with the final recruitment sample as shown in Table 5 (Pilot Phase households are included with Phase I).

Unfortunately, the recruitment occurred in small bursts, and installations occurred over a much longer time-period. This lag made it difficult to determine the actual response rate by sample group as defined in Table 5. Although households agreed to participate and provided household socio-demographic information, this did not guarantee their participation in the required instrumentation component. Table 6 gives the rates for recruited/opted out and recruited/installed/retrieved for both recruitment phases. Regardless of meeting the minimum recruitment criteria, low-income households did not participate at the same rate in the instrumentation component as higher income households. Low-income households had the highest opt-out rate at 63%. The time between contact and installation may have negatively affected the installation rates overall. Additionally, 10% of the household income levels were unknown until after the

2004 Spring Travel Diary Survey collection. At this point, the research team had completed equipment installations and it was too late to recruit households into the low response cells. The overall recruitment completion rate was 54.3%.

Table 6 Overall Opt Out and Installation Rates for All Household Recruits

Sample Group (Income, HH Size, # Vehicles)	Total Recruited	Phase I		Phase II		Phase I and II Total	
		Recruited and Opted Out	Recruited and Installed	Recruited and Opted Out	Recruited and Installed	% Recruited and Opted Out	% Recruited and Installed
1 <30k, Any, 1+	55	22	15	13	5	63.6%	36.4%
2 30-75k, 1, 1+	59	16	21	9	13	42.4%	57.6%
3 30-75k, 2+, 1	46	13	9	15	9	60.9%	39.1%
4 30-75k, 2, 2+	62	18	23	6	15	38.7%	61.3%
5 30-75k, 3+, 2+	71	17	19	20	15	52.1%	47.9%
6 75+, 1, 1+	12	7	5	0	0	58.3%	41.7%
7 75-100k, 2+, 1+	63	22	39	0	2	34.9%	65.1%
8 >100k, 2+, 1+	102	29	73	0	0	28.4%	71.6%
99 Ukn, Any, Any	24	14	3	5	2	79.2%	20.8%
	494	158	207	68	61	45.7%	54.3%

The level of low-income (<\$30,000) households that were fully installed, and for which diary data was obtained, was lower than expected in the study. This is due to a combination of the incidence of low-income households with one or more vehicles, lower completion rates during the vehicle installation phase, and lower completion rates among installed households during the trip retrieval stage. The sample design for the Value Pricing Study required the recruitment of low income households in sufficient numbers to

support a minimum of 30 fully installed low income households as part of the overall sample design and analysis requirements. Surveyors successfully recruited 55 low-income households into the study; however, only 20 of the 55 completed the installation component.

Identification of low-income households is challenging in any telephone-based survey since even with the latest Census information, household income levels are at aggregate geography levels. As part of the overall sample strategy, low-income Census tracts were over-sampled in an effort to increase the available pool of low-income households for participation in the study. However, this group historically has the lowest participation rates in even the most basic research programs. The level of participation effort required in this study and the absence of incentives made the full recruitment of low-income households challenging.

The percent of population for this target demographic for the Atlanta region is 21%. However, this does not take into account the level of zero household vehicles within this group (~ 8%). Overall, the percentage of available households meeting the low income criteria is approximately 13 percent. The proportion (7.5%) of low-income households completing the study is low in comparison, even with extensive over-sampling and multiple (12 or more) contact attempts.

Both retrieval rates and installation rates were lower for the low-income household group. Going into the study, the recruitment firm knew that over-sampling and over recruitment would be necessary to achieve the required number of fully participating low-income households. However, the participant requirements in this pioneering study are

unique and the full impact of the study design on participation rates for different demographic groups was relatively unknown at the onset.

Given all of the previous information on recruitment status for the Commute Atlanta program, it is important to consider how all of this affects the ability of this research to accurately quantify and reflect driver speeding behavior. However, there are other factors directly related to the useful sample regarding identification of shared vehicles (through travel diary reporting), the operation and functionality of in-vehicle equipment, and the validity of the data contained in the trip files reported by the equipment. Due to these interactions, a special section in the data processing and sample selection chapter reviews the effects of all of these items on the potential driver pool and trip data available for speed data analysis.

Travel Diary Response Rates

The recruitment and completion figures for the 2004 Spring Travel Diary Survey are shown in Table 7 and Table 8. Table 7 provides the overall recruitment and retrieval rates. There is a column entitled ‘Not Recruited’ showing 27 households as not recruited for the spring diary survey. Unfortunately, the recruitment firm did not include the original Pilot Phase participants in the sample. Therefore, only seven households were officially not recruited into the study. The reasons for this are unknown, but are most likely attributable to difficulties in contacting households – either because members of the household were screening calls or were out of town at the time of contact.

Table 7 Spring 2004 Travel Diary Recruitment and Retrieval Rates

Sample Group (Income, HH Size, # Vehicles)	Total Sample	Not Recruited	% Not Recruited	Recruited Retrieved	% Recruited Retrieved	Recruited Not Retrieved	% Recruited Not Retrieved
1 <30k, Any, 1+	20	5	25.0%	12	60.0%	3	15.0%
2 30-75k, 1, 1+	34	3	8.8%	27	79.4%	4	11.8%
3 30-75k, 2+, 1	18	3	16.7%	14	77.8%	1	5.6%
4 30-75k, 2, 2+	38	1	2.6%	31	81.6%	6	15.8%
5 30-75k, 3+, 2+	34	2	5.9%	25	73.5%	7	20.6%
6 75+, 1, 1+	5	1	20.0%	2	40.0%	2	40.0%
7 75-100k, 2+, 1+	41	2	4.9%	29	70.7%	10	24.4%
8 >100k, 2+, 1+	73	8	11.0%	45	61.6%	20	27.4%
99 Ukn, Any, Any	5	2	40.0%	0	0.0%	3	60.0%
	268	27	10.1%	185	69.0%	56	20.9%

Table 8 shows the recruitment and retrieval rates by recruitment Phase. Some of the non-response is attributable to the added burden for households who had previously completed the summer travel diary as shown in the differences between Phase I and Phase II completion rates, 65.7% and 80.3% respectively.

Table 8 Spring 2004 Travel Diary Recruitment and Retrieval Rates
(Phase I and Phase II Separated)

Phase I							
GTSample	Recruited Phase I	Not Recruited	% Not Recruited	Recruited Retrieved	% Recruited Retrieved	Recruited Not Retrieved	% Recruited Not Retrieved
1	15	4	26.7%	10	66.7%	1	6.7%
2	21	2	9.5%	15	71.4%	4	19.0%
3	9	2	22.2%	6	66.7%	1	11.1%
4	23	1	4.3%	17	73.9%	5	21.7%
5	19	2	10.5%	13	68.4%	4	21.1%
6	5	1	20.0%	2	40.0%	2	40.0%
7	39	2	5.1%	28	71.8%	9	23.1%
8	73	8	11.0%	45	61.6%	20	27.4%
99	3	2	66.7%	0	0.0%	1	33.3%
Total	207	24	11.6%	136	65.7%	47	22.7%
Phase II							
Sample Group	Recruited Phase II	Not Recruited	% Not Recruited	Recruited and Retrieved	% Recruited and Retrieved	Recruited Not Retrieved	% Recruited Not Retrieved
1	5	1	20.0%	2	40.0%	2	40.0%
2	13	1	7.7%	12	92.3%	0	0.0%
3	9	1	11.1%	8	88.9%	0	0.0%
4	15	0	0.0%	14	93.3%	1	6.7%
5	15	0	0.0%	12	80.0%	3	20.0%
6	0	0	0.0%	0	0.0%	0	0.0%
7	2	0	0.0%	1	50.0%	1	50.0%
8	0	0	0.0%	0	0.0%	0	0.0%
99	2	0	0.0%	0	0.0%	2	100.0%
Total	61	3	4.9%	49	80.3%	9	14.8%

The travel diaries provide a very important function for the speeding behavior study. Based on the revealed driver and vehicle combinations, vehicles shared between multiple drivers can be removed from the potential study sample. This reduces the chances that models would be developed with inaccurate data. Data from the summer and spring diaries, as well as a response from the recruitment activities are all used as screening tools for determining appropriate driver identities.

Vehicle Instrumentation

Georgia Tech researchers developed an in-vehicle instrumentation package to provide a robust data collection platform (Figure 10). The Linux-based 386 computer operates on 12V vehicle power (with an extremely low power draw when the vehicle is not in operation). The entire system is packaged in an aluminum extrusion case, approximately 8" by 6" by 2". Installers typically place the device under the vehicle seat or on the floorboard under the dashboard on the passenger's side. The device connects to constant power, switched power, and ground.



Figure 10 GT Trip Data Collector In-Vehicle Instrumentation

The GT Trip Data Collector equipment hardware and connections include:

- CPU, with 386 architecture running Linux operating system,
- 12 – Volt power input with 3 mA draw,
- Ignition sensor input wire,

- Global Positioning System (GPS) receiver,
- TDMA cellular transceiver,
- On-board diagnostic connection (OBD),
- 2 – Serial Ports (one supporting the OBD, one extra),
- 6 – I/O Connections (including vehicle speed sensor (VSS)),
- Cellular antenna,
- GPS antenna, and
- Optional LCD display (not deployed in Commute Atlanta Phase I).

Figure 11 shows the GT Trip Data Collector with all wiring and antennas. Full specifications for the GT Trip Data Collector are located in Appendix D along with specifications for the SirfStar II eLP GPS receiver and the Ericsson DM 15 TDMA cellular transceiver.

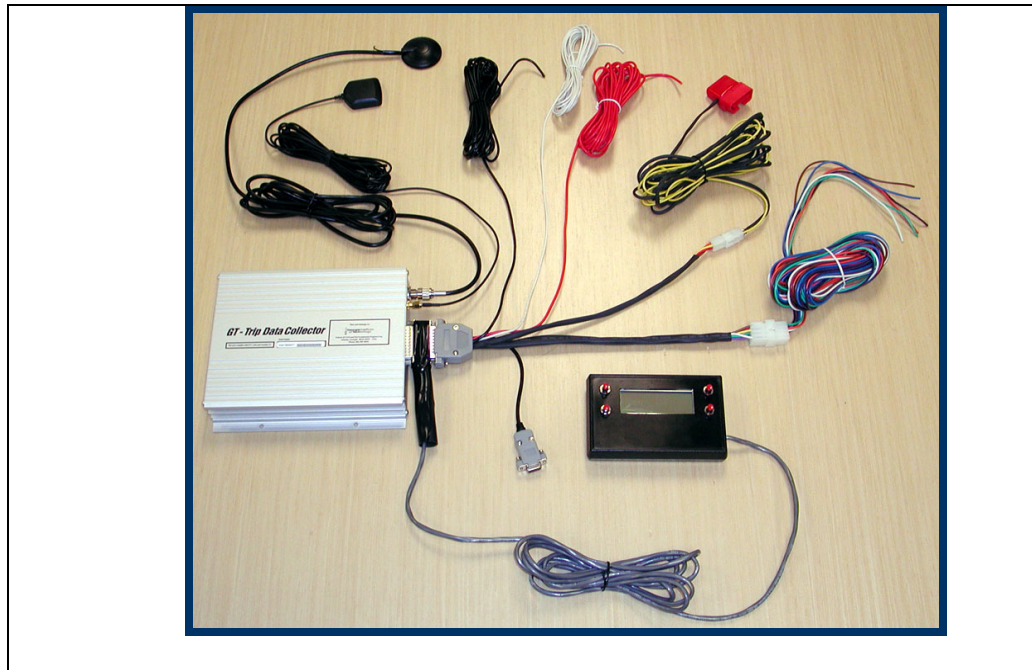


Figure 11 GT Trip Data Collector with Wiring Harnesses and Antennas

The onboard equipment monitors engine start date and time, second-by-second vehicle position (latitude and longitude), heading, and speed. The number of satellites and GPS signal quality indicators are also collected and used in route matching routines. A vehicle speed sensor (VSS) wire connection is also included on 170 vehicles providing a secondary data stream for speed, and thereby provides a more accurate calculation of acceleration than is available using the GPS system. For many post-1996 model year vehicles, the equipment also provides up to ten engine and emissions-related parameters from the onboard diagnostics system via a direct connection to the onboard diagnostics engine computer (OBD-II) port. For each engine ignition event, the equipment starts and saves a trip file. The trip file remains open recording second-by-second operations data until the vehicle operation stops and the driver shuts off the engine. Essentially, every engine on/off pair generates one trip file (See Figure 12). Intermediate stops, where the engine remains on, can also be identified in the data (Li, 2004). A complete listing of the elements contained in the trip file are in Appendix E.

Trip Reporting

Trip data are currently transmitted during the off peak cellular period (10 p.m. to 6 a.m. weekdays and anytime on weekends between 10 p.m. Friday and 6 a.m. Monday), once weekly, via the cellular connection. Each vehicle reports when polled via a short message system (SMS) or e-mail text message command. Researchers can send messages to the unit automatically from a server operation, or manually through an email interface. Hence, the units can report at any desired frequency (limited only by SMS message delay via cellular system and the Internet). A tracking command also allows the researchers to trigger the box to report its location in real time for a set period and frequency, for use in

tracking a stolen vehicle or to examine the congestion conditions on a specific roadway at a given time. The result is that the box sends SMS to email messages one after another at the chosen rate reporting the vehicles' position in latitude and longitude. All systems are remotely configurable via SMS, allowing the researchers to select alternative data streams for monitoring or changing data capture frequency (maximum frequency for GPS is 1 Hz, speed wire up to 4 Hz). The onboard software can also be upgraded remotely by transmitting new software to the device via the cellular connection through the circuit-switch data channel.

Data are stored in a flat file structure for each vehicle trip to facilitate data analysis. Researchers post-process each trip to calculate basic trip-level summary statistics. Trip origin and destination position can be linked back to trip purpose for more than half of the trips, using basic latitude and longitude coordinates and information collected during the standard two-day household diary study (Wolf, 2001). Trips per day, trip distance, and average trip speed are readily determined by examining trip summary data. Integrating the vehicle speed trace allows calculation of trip length. Researchers use the basic data stream to examine vehicle speed and acceleration for any portion of a vehicle trip or the whole trip.

Optional Features

A standard RS-232 computer communications port enables the onboard equipment to send and receive data to and from almost any additional computing or scientific device carried aboard the vehicle. Researchers have demonstrated this capability by integrating data from a SEMTECH-D (Sensors, Inc.) emissions measurement system and from a

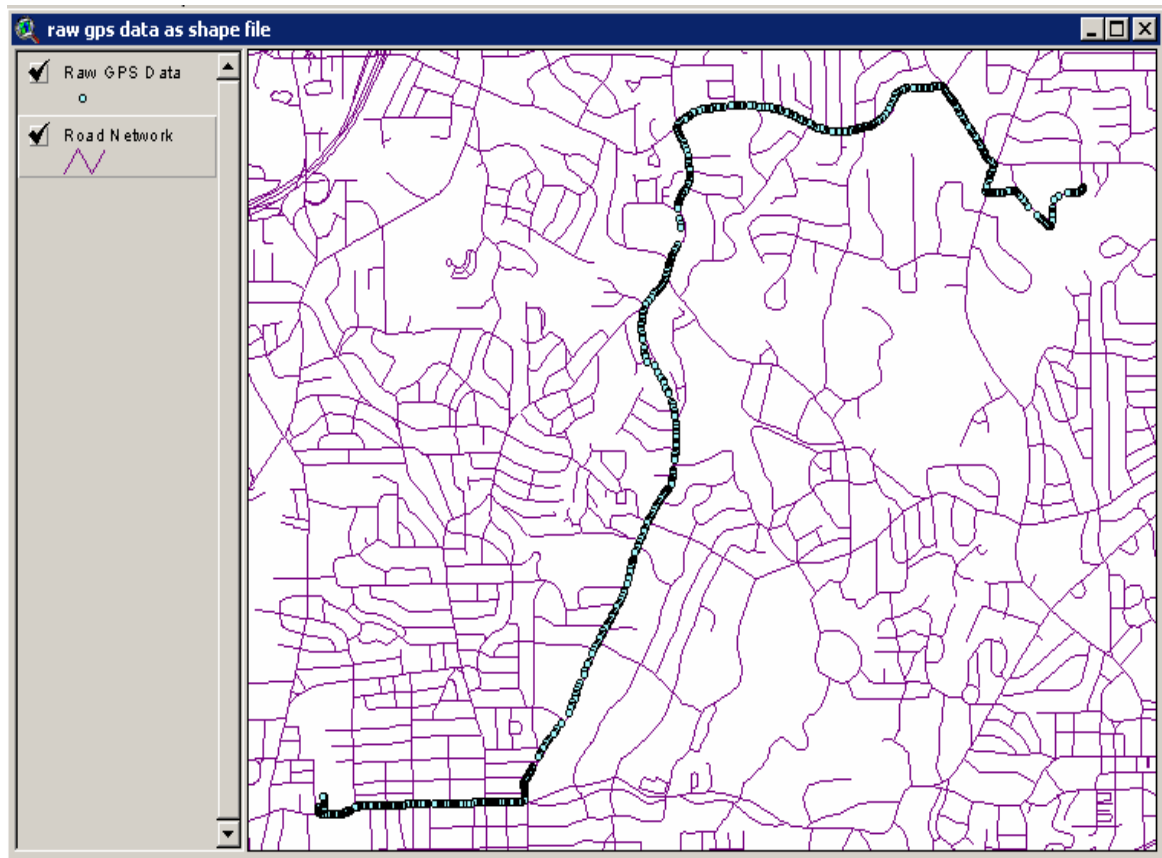


Figure 12 Trip File shown on GIS map

MARTA heavy-duty diesel bus engine (Guensler and Ogle, 2003). Six additional digital data lines (programmable with 4 inputs and 2 outputs) allow researchers to collect information from on-off sensors (e.g. seat-belts, headlights, windshield wipers, brakes, air conditioning, etc.) and could be used to turn on or off additional onboard devices (e.g. door locks or equipment). Although these six supplemental data lines were not used in the Commute Atlanta deployment due to budget constraints, the data lines can be readily connected to such onboard systems at a later date. A data terminal capability allows researchers to add a LCD terminal to each in-vehicle device so it can receive text messages and send push button responses back to the trip logger.

Engine Computer Monitoring Capabilities

The GT Trip Data Collector is equipped with OBD monitoring capabilities. Using chipset technology licensed from an independent contractor and imbedded in the circuit board, the GT Trip Data Collector can collect up to 10 engine parameters at up to 1Hz. Standard Hex Code commands are used to poll the OBD system for the desired parameters. Hence, the monitored parameters, and the polling frequency, can vary from vehicle to vehicle to meet specific research objectives. The software is also structured such that researchers can change the parameters monitored, or data polling frequency, by sending SMS text message commands.

Table 9 contains a list of the standard OBD commands that are often available for 1996 and later model year vehicles. The actual OBD parameters available vary by manufacturer, make, model, and model year. The onboard diagnostic parameters currently included in the Commute Atlanta study (when each parameter is available on the vehicle) are identified in the table in bold.

Other OBD parameters can be monitored, provided that the correct Hex Code command can be integrated into the software for each make, model, and vehicle year. The Commute Atlanta study budget constraints allowed 350 devices to be equipped with an OBD wiring harness, so not all post-1996 vehicles in the study include OBD-II monitoring. The OBD data streams allow researchers to examine driver-vehicle interactions. Figure 13 illustrates the linkages that can be made between trip purpose, roadway type, and engine operating parameters.

Georgia Department of Motor Vehicle Safety (DMVS) Crash Database

During the consent process of the recruitment, researchers asked permission from participants to obtain their Georgia Driver History Records. However, after reviewing the limited information contained in the driver history files as presented earlier in the literature review section, the information was not deemed useful for the associated cost of \$5 per record. The biggest issue with the database is the lack of complete crash information. The DMVS only includes crashes on a drivers' record if that driver received a citation and the citation resulted in conviction. A thorough driver speeding profile required more complete crash information.

Table 9 OBD Parameters Available for Vehicle Years 1996 and Later

<i>OBD I and OBD II</i>	<i>OBD II Only</i>
Battery voltage too high	3-4 shift solenoid (transmission)
Camshaft position sensor	Ambient temperature sensor
Charge air temp sensor	Aspirator solenoid: Electric air pump
Charging system inoperative	Cam/crank misalignment
Crankshaft position sensor	Catalyst efficiency
Distributor signal	Duty cycle purge solenoid
Engine coolant sensor	Evaporative system small and large leaks
Engine thermostat operation	Fuel level sensor
Evaporative purge solenoid	Governor pressure battery volt relay (transmission)
Exhaust gas recirculation system	Governor pressure control solenoid (transmission)
Fuel injector circuit	Governor pressure sensor (transmission)
Fuel system lean	Individual cylinder misfire
Fuel system rich	Lead detection pump solenoid (evaporative)
Idle air control motor	Leak detection pump pressure switch (evaporative)
Ignition coil(s)	Multiple cylinder misfire
Manifold absolute pressure sensor	Output shaft speed
Oxygen sensor(s)	Park/neutral switch
Powertrain control logic circuitry	Part throttle unlock solenoid
Throttle body surface temperature	Power steering pressure switch
Throttle position sensor	Secondary air flow
Vehicle speed sensor	Signal access (Cal ID # version of software)
	Stop lamp switch
	Synchronous (cam/crank)
	Transmission oil temperature sensor

Source: Chrysler 1996

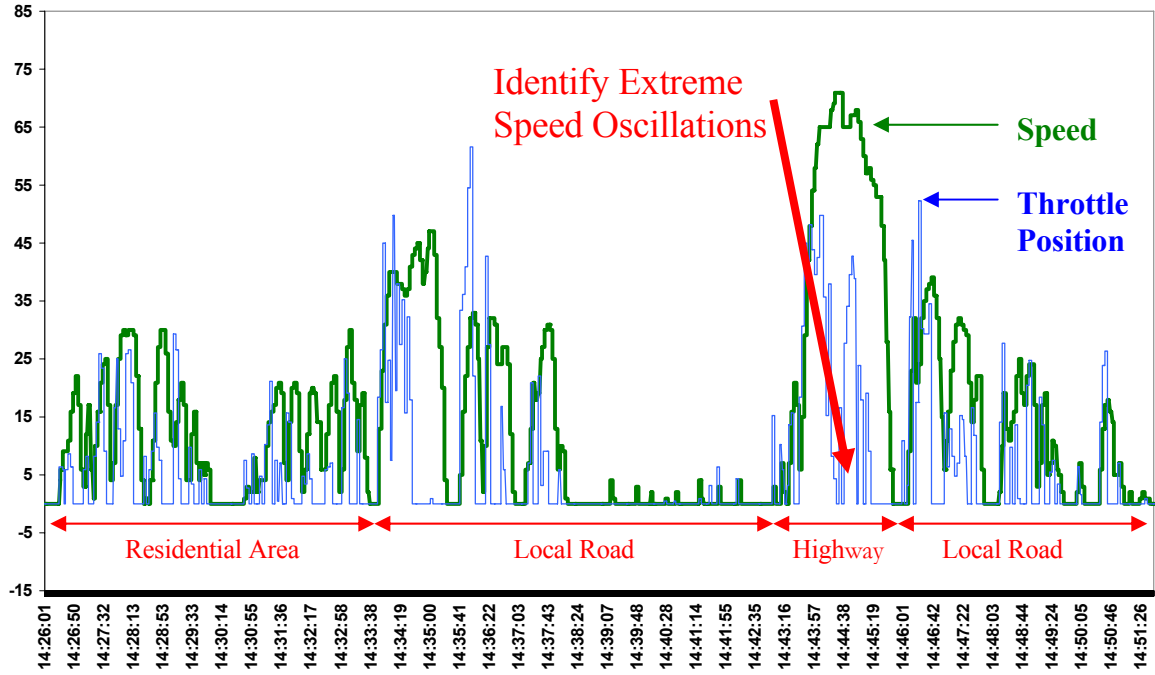


Figure 13 Speed and Throttle Position Trace from OBD Data Stream

The raw crash databases contained all of the information necessary to match study participants to specific crashes, and therefore researchers obtained crash databases for the years 1993-2004 for the State of Georgia from the DMVS. The files maintained by the DMVS contain personally identifiable information. For the purposes of this research, the permission was obtained to use the personally identifiable information to match the study drivers to crash involved drivers for the past 4 years (2000-2003). The crash database contains the drivers first, last and middle name, date of birth, VIN, vehicle registration county, license plate number, vehicle make, vehicle model, and vehicle model year. With the exception of date of birth, the Commute Atlanta data contains the same data elements. In lieu of the date of birth, the researcher developed a simplified birth year query based on the drivers reported age as a substitute data source. Using all of these pieces of

information, drivers from the Commute Atlanta program were matched to crash-involved drivers in the crash data files. This was a very time consuming and manually intensive process.

The process included several levels of queries developed through trial and error. The first query used license plate numbers to join the two tables in access. All matches considered successful contained a minimum of three pieces of information. In the case of the license plate, matching pieces typically included driver name and vehicle make and model information. The second query used VIN, and third used name, birth year and county of vehicle registration/county of residence. In many cases, the author discovered slight errors in names and VIN numbers of one or two characters, and verified these probable matches by visual inspection. Ultimately, the author identified 198 participant crashes. A secondary match between multiple-crash drivers, as well as a thorough visual inspection of the records resulted in the elimination of 9 records. The final participant crash count for the four years totaled 189 crashes.

Table 10 shows the number of Georgia crashes by licensed driver for the 13-county Atlanta area. The percent of drivers in the 13-county area involved in crashes in 2002 was 11.23%. Similarly, crashes involving Commute Atlanta drivers were divided by the number of potential drivers in each year based on license status and birth year. Table 11 depicts the results of this analysis. The crash rate for 2002 is close to that determined from the 13-county dataset. Researchers noted that 2003 involved fewer crashes than 2002, which may be due to error or missing data from the 2003 dataset. The 2003 crash data were still preliminary at the time of analysis, but considered 90% complete by DMVS.

Fewer crashes from earlier years may be due to changes in vehicles, license plates, residences, and name changes in the case of marriage, divorce, etc. These data will be matched against that of the participant survey for further analysis.

Table 10 2002 Georgia Crash Rates per Licensed Driver for the 13-County Atlanta Area

County	Licensed Drivers	Drivers in crashes	Percent
CHEROKEE	130,507	7969	6.11
CLAYTON	186,789	23921	12.81
COBB	529,761	53503	10.10
COWETA	76,062	5967	7.84
DEKALB	522,929	64798	12.39
DOUGLAS	82,583	8439	10.22
FAYETTE	85,708	5505	6.42
FORSYTH	86,502	7136	8.25
FULTON	632,636	97304	15.38
GWINNETT	520,884	53728	10.31
HENRY	113,111	11291	9.98
PAULDING	71,967	2986	4.15
ROCKDALE	63,782	6095	9.56
	3,103,221	348642	11.23

Table 11 Commute Atlanta Crash Rates per Potential Driver Population

Year	Potential Driver Population from Commute Atlanta Study	Number of Crashes	Crash Rate per Potential Commute Atlanta Licensed Driver
2000	477	38	8.0%
2001	488	47	9.6%
2002	500	55	11.0%
2003	504	49	9.7%

The Georgia Crash Database contains information on motor vehicle crashes that occur on public roadways and produce damages of \$500 or more. Information on the crash,

vehicles and people involved in crashes comes directly from the DMVS 523 crash report form and is based on the information collected by the officer at the scene of the crash. As per Georgia Code § 375-6-2.02, DMVS is the custodian of crash records. The completion of the *Georgia Uniform Vehicle Accident Report* (DMVS 523) is required for every crash resulting in death, injury, or property damage in excess of \$500. All law enforcement agencies are required to submit completed forms to DMVS.

The DMVS crash database documents the consequences of crashes (fatalities, injuries, property damage, and violations charged) based on the information contained in the Georgia 523 form. The database includes the roadways, vehicles, and people (drivers, occupants, pedestrians) involved in the crash, documents the consequences of the crash (fatalities, injuries, property damage, and violations charged), and documents the time, location, environment, and characteristics (sequence of events, rollover, etc.) of a crash.

The database contains over 100 data elements including driver characteristics (e.g., age or gender), location characteristics (e.g., roadway type, traffic flow and specific intersections), vehicle characteristics (e.g., type, condition and legal status), environmental (e.g., time of day, day of week, weather), and behavioral characteristics (e.g., driver actions, pedestrian actions, etc.).

In addition to providing information on a particular crash, the crash records system supports analysis of crashes in general and crashes within specific categories defined by: person characteristics (e.g., age or gender), location characteristics (e.g., roadway type or specific intersections), vehicle characteristics (e.g., type, class and weight), and the

interaction of various components (e.g., weather, driver actions, pedestrian actions, driver error etc.).

The DMVS crash database contains basic information about every reportable motor vehicle crash resulting in at least \$500 damage on any public roadway in the state. Analysts in the DMVS collect additional information as necessary for crashes involving fatalities in order to meet the requirements of the Fatality Analysis Reporting System (FARS). In addition, Georgia participates in the State Data System by providing an annual extract of crash data to the National Highway Traffic Safety Administration (NHTSA). It conforms to the Model Minimum Uniform Crash Criteria (MMUCC), a guideline for a suggested minimum set of data elements to be collected.

Commute Atlanta Participant Survey

The research protocol approved by the IRB allows for one interview every six months with the households. All materials used in the interviews are subject to review. Given the time consumption of contacting households via telephone, researchers applied for an amendment to the original protocol to allow the initial survey to be mailed out and mailed back with the allowance of phone contact for item non-response and clarification. The first survey, scheduled for late summer 2004, was delayed for a full IRB board review of the research protocols and survey instrument. The survey was mailed in early November 2004. The objective of the survey was to obtain up-to-date information on the household vehicles, to ascertain if any vehicle ownership or use patterns had changed, and whether any persons had left or joined the household. A secondary portion of the survey requested that household participants of driving age complete a section of self-reported crash and

speeding citation involvement. The self-reported crash and citation information serves to verify the information obtained from the DMVS.

The following questions were given to each driver in the household:

- How long have you had a drivers license?
- How many speeding tickets have you received in the last 5 years? ...in your lifetime?
- How many crashes have you been involved in as a driver during the study period? ...in the last 5 years? ...in your lifetime?
- If you were involved in one or more crashes within your lifetime, how many crashes were you found to be at fault for? How many crashes involved injuries?
- When driving, do you tend to pass other cars more often than other cars pass you?
- On a regular basis, do you drive faster than the posted speed limit?
- In general, how do you feel about posted speed limits? (too high, about right, too low)
- How often do you wear your seat belt? (always, most of the time, sometimes, rarely, never)

Researchers constructed these survey questions to obtain information linked with various driving behaviors including speeding and crashes. A copy of the full survey and cover letter are in Appendix F.

Georgia Department of Transportation

Crash Location Information

The Georgia Department of Transportation (GDOT) is responsible for managing the safety of the roads that they build and maintain. In response, GDOT maintains crash information for all roadways state-owned, operated, and otherwise. DMVS transfers the majority of the crash data to the GDOT. GDOT adds the crash location, coded to their state roadway network coordinates, and maintains the repository of crash location information for the state. Researchers obtained the location data for the years 2000-2002 from GDOT for use in the speed and crash analysis. The crash location information allows linkage of the crash data to the roadway characteristics file described below. With this information, researchers can determine functional class and posted speed limits of roads where the crashes occurred. Analysis of driver speeding exposure on certain functional classes in conjunction with crashes on those same functional classes would make a compelling argument for driver speeding behavior modification.

Roadway Maps and Associated Network Characteristics

The final source of data and one of the most important is the Roadway Characteristics (RC) file and associated map files from GDOT. The RC file contains roadway characteristics for all roadways in the state. The State has contracted the update of the route layer (map file) for the newest version of the RC file to the University of Georgia (UGA). This version should be complete in October 2005. The roadway characteristics file is important, because it allows researchers to compare observed speed and the posted speed for the roadway. The GPS location data for each trip from each vehicle is matched to roadway routes traversed in the official GDOT roadway characteristics database.

Georgia Tech researchers developed these processes using proprietary GIS software by ESRI. The map matching techniques take every second of trip data and link the data to specific roadway links in the modeled transportation network (by roadway classification identification number and milepost).

By comparing observed driver speed on each transportation link to the posted speed limit in the roadway characteristic database, nearly every second of vehicle activity can be determined under or over the speed limit (and by how much). Table 12 provides a summary of speeding information developed for a subset of the vehicle fleet. In Figure 14, the horizontal axis indicates the posted speed limit. Each bar represents the percentage of total operating time that the subset of vehicles spend on facilities with the indicated posted speed limit. The shaded portions of each bar indicate the magnitude of speeding that occurs on each of these facility groups. It is clear that a significant fraction (44%) of vehicle operating time in Atlanta is spent above the posted speed limit.

Table 12 Seconds of Active Driving Time and Speeding Activity by
Posted Speed Limit

Posted Speed Limit	Percent of Posted Speed Limit Exceedence									
	<= PSL	(0~5]	(5~10]	(10~15]	(15~20]	(20~25]	(25~30]	(30~35]	(35~40]	40+
25	56.04	13.79	8.63	5.64	5.04	4.19	2.54	1.58	1.17	0.01
30	56.12	17.63	11.60	5.53	3.08	2.04	1.48	1.14	0.80	0.02
35	51.69	17.09	14.56	7.56	3.50	1.83	1.34	1.05	1.02	0.05
40	59.02	18.84	12.91	5.18	1.71	0.99	0.69	0.43	0.18	0.00
45	65.02	16.42	10.72	4.80	1.72	0.73	0.40	0.13	0.03	0.00
50	75.79	12.20	6.50	2.75	1.30	1.12	0.28	0.01	0.01	0.00
55	46.33	11.20	13.07	13.25	10.41	4.49	1.08	0.13	0.02	0.00
60	38.58	14.89	21.42	18.54	4.69	1.14	0.02	0.00	0.00	0.00
65	49.78	18.67	19.48	9.86	2.01	0.16	0.02	0.00	0.00	0.00
70	45.67	19.51	25.88	7.17	1.04	0.32	0.27	0.04	0.00	0.00

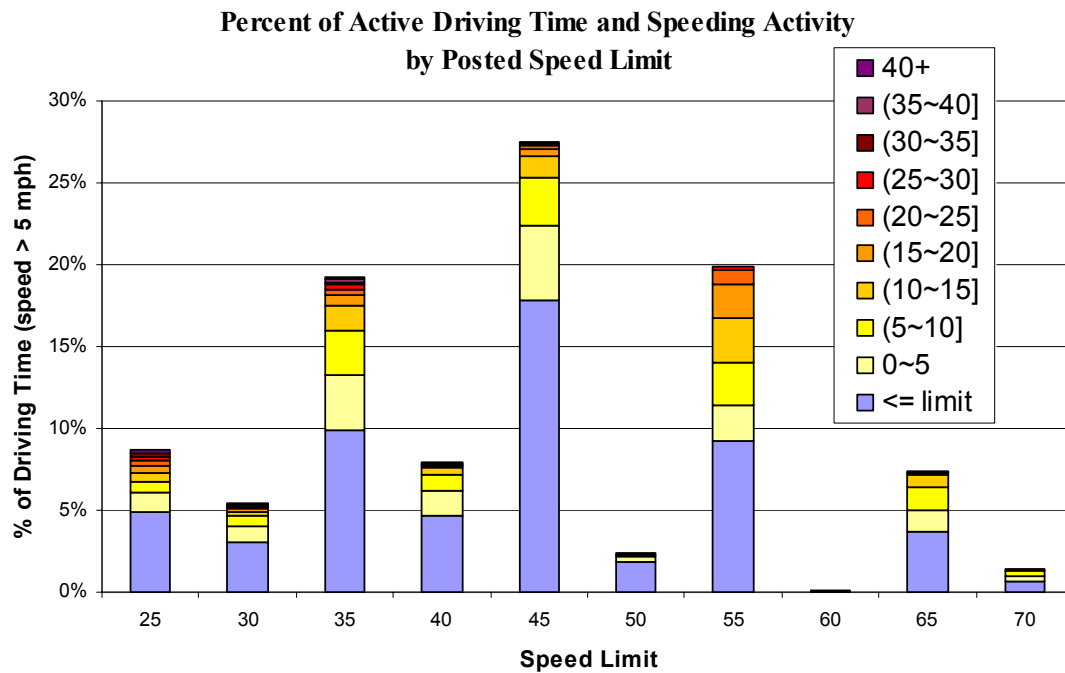


Figure 14 Percent of Active Driving Time and Speeding Activity by
Posted Speed Limit

Once the data were processed to the GIS, all of the previously analyzed vehicle trips were then sorted according to roadway classification and linked to specific roadway characteristics (such as roadway classification, speed limit, number of lanes, median type, etc.). Travel characteristics, such as turns per trip or mile can then be quantified. Supplemental GIS processing is resource intensive (labor and computer processing time); however, the analysis potential provided by this exercise is limitless.

Chapter Five

DATA PROCESSING

Recall from introduction that behavioral safety programs operate based on measuring and monitoring safe behavior performance. The opposite of safe behavior is at-risk behavior, which Krause (1997) defines as behavior that has been identified as critical to safe performance. The critical behavior for this research is that of driver compliance with posted speed limits and legislated enforcement limits. Speeding behavior is measured in seconds of vehicle operation where the driver's speed is in excess of the posted speed limit. Due to the limitations of geographic information system, comparisons of driver speed to the posted speed limit are confined to the 13-county study area. Although some posted speed limits may be lower than the safe travel speed for the roadway, general trends of vehicle operation at speeds well above the posted speed limit are indicative of aggressive driver behavior. A key concept for the research, taken from behavioral safety analysis, is the calculation of safe behavior performance using a percent safe value calculated as follows.

$$\text{Driver X \% Safe} = \left(\frac{\text{count of safe behavior}}{\text{count of safe behavior} + \text{count of at - risk behavior}} \right) (100)$$

One difference between this research and that of industrial behavioral safety programs, is that the risk of crashing due to speeding behavior has yet to be determined. Therefore, without the knowledge of the level of risk associated with speeding behavior, speeding behavior herein is not defined as safe, unsafe, or at-risk, but rather in terms of compliance. In Georgia, most police officers may only cite drivers if they are found to be

speeding more than 10 mph above the posted speed limit. Therefore, this research looked at trips that deviated more than 10 mph above the limit vs. trips that do not exceed this threshold. The measure of behavior performance is therefore call percent compliance. The first requirement for this calculation is to identify the subject driver with some certainty. The second requirement is to obtain valid and reliable measurements of speeding behavior performance. The following section provides an analysis of driver speed measurement accuracy as well as quality analysis and quality control of associated geographic road characteristics. Subsequent sections include information for the required processing steps and filters used to determine the research sample.

Data Quality

Three data quality issues must be addressed prior to data processing and sample selection. These include:

- Verification of GPS speed from instrumented vehicles to be representative of actual driving speed,
- Verification of the information in the roadway characteristics file to be representative of actual posted speed limits found on roadway network, and
- Verification of the accuracy and completion of the roadway network maps used as the underlying structure of the GPS to GIS map-matching process.

Each of these issues are discussed in detail in the following sections.

Verification of GPS Speed

Obtained from the instrumented vehicle trip files, the measure of driver speed is the most critical piece of information in this analysis. The driver speed is generally recorded

from direct GPS measurements. The Sirf Star II GPS receiver used in the in-vehicle instrumentation provides an accuracy rating of 0.2236 mph (0.1 mps) for speed under normal operation without the intentional government/military degradation, Selective Availability (SA) (Sirf, 2004). However, the unit employs a proprietary smoothing algorithm and there are known variances when the GPS speed drops below 5 mph. Previous research (Ogle et al., 2002) validated the use of the GPS for driver performance studies using data from similar GPS data collection equipment. The results of the study showed the GPS measured speeds to be within 1.1mph of the distance-measuring instrument (DMI), on average. Given the importance of the GPS speed for this application, additional accuracy tests were undertaken and reported elsewhere by Jun et al. (2004). The following provides a brief summary of the analysis and results.

The Commute Atlanta instrumented vehicle fleet provides a unique opportunity to explore the validity of GPS measurements. Along with GPS, speed data from the vehicle speed sensor (VSS) wire and on-board diagnostics (OBD) system are also available, although ultimately, both data sources originate from the VSS. The VSS basically measures distance traveled by counting revolutions of the transmission using magnetic sensors. The OBD system (a component of the engine computer) samples speed from the VSS on a 4-6 second interval. Figure 15 shows GPS and OBD measurements from a single trip by time. Visually, these two data streams seem to correlate well.

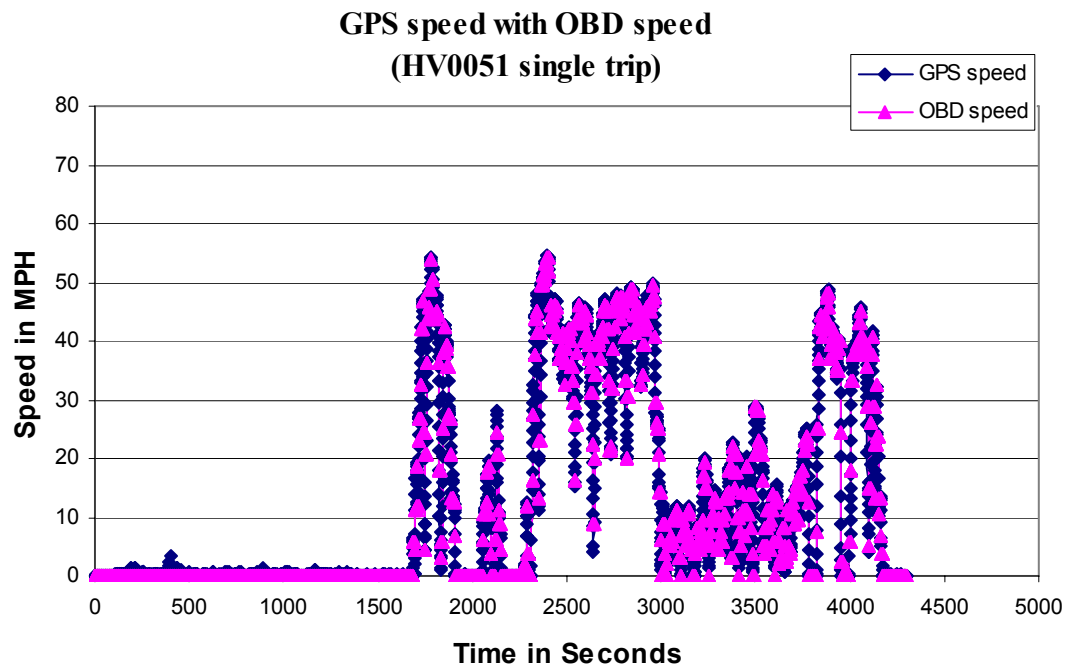


Figure 15 GPS speed with OBD speed (one trip)

To verify the accuracy, researchers completed three separate tests:

- Bench test of GPS,
- Field test of VSS, and
- Field test of OBD.

Bench Test of GPS

The bench test of GPS involved collecting data at a stationary location for a period of 31 hours. The actual speed in this scenario is known, and equal to zero. From past experience, speed values in the range of 0-5 mph have consistently had higher rates of error than observed at higher speeds. This is in part due to proprietary smoothing algorithms, which require accurate heading information. When speeds drop below 5 mph, the device cannot accurately discern the heading therefore impeding its ability to self-correct. During

the bench test, 114,014 GPS speed measurements were collected. Figure 16 shows the speed error histogram and the cumulative error probability plot. The mean GPS speed during the stationary test was 0.25 mph. This is very close to the reported accuracy of the unit, 0.2236 mph. The probability plot shows that the speed error is within 0.5 mph 90% of the time. The probability of observing the maximum error of 2.15 mph approaches zero. Speed errors are within 1 mph or better than 99% of the time.

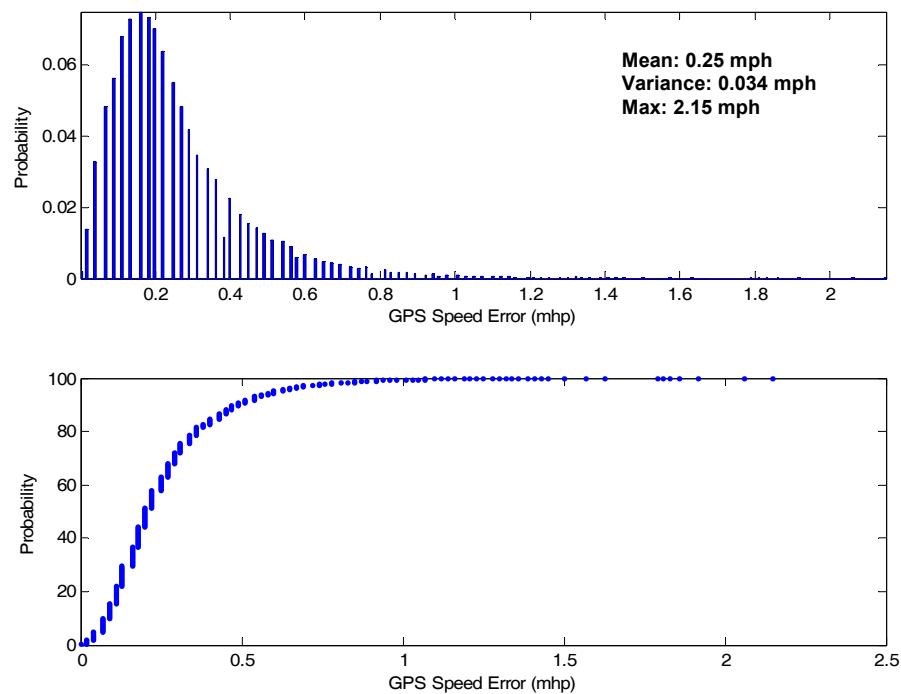


Figure 16 Stationary Test Results for GPS Speed

Field Test of VSS

The second test between GPS and VSS used 1-month of data from five different vehicles. In general, vehicle manufacturers use standard revolution counts for calculating a distance of 1 mile (i.e., 2,000 wheel-ticks/mile, 4,000 wheel-ticks/mile, or 8,000 wheel-ticks/mile) based on sensor spacing. These are vehicle dependent, and only provide the

basis for the calculation. Variation in tire size or pressure from the manufacturer specifications will change these values. Additionally, variation can occur between and within trips, as tire temperature increases at higher speeds. Figure 17 shows a comparison of GPS speed and un-calibrated VSS speed. Using this comparison to determine GPS speed error would falsely attribute large positive errors to GPS, especially at higher speeds, as shown in Figure 18.

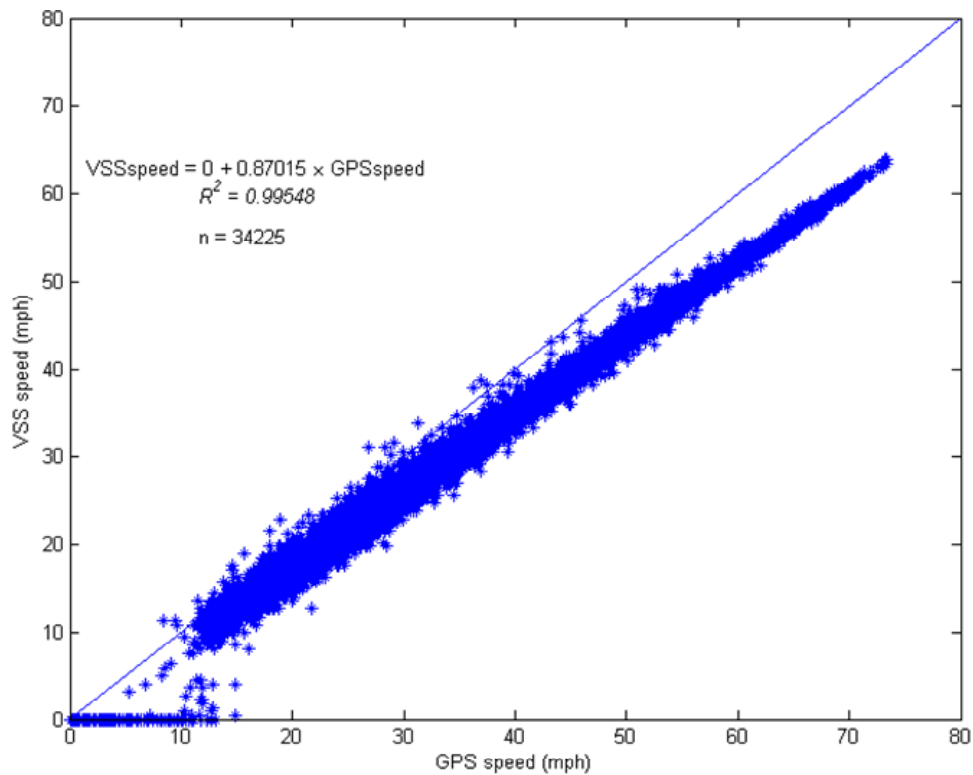


Figure 17 Uncalibrated VSS Speed vs GPS Speed

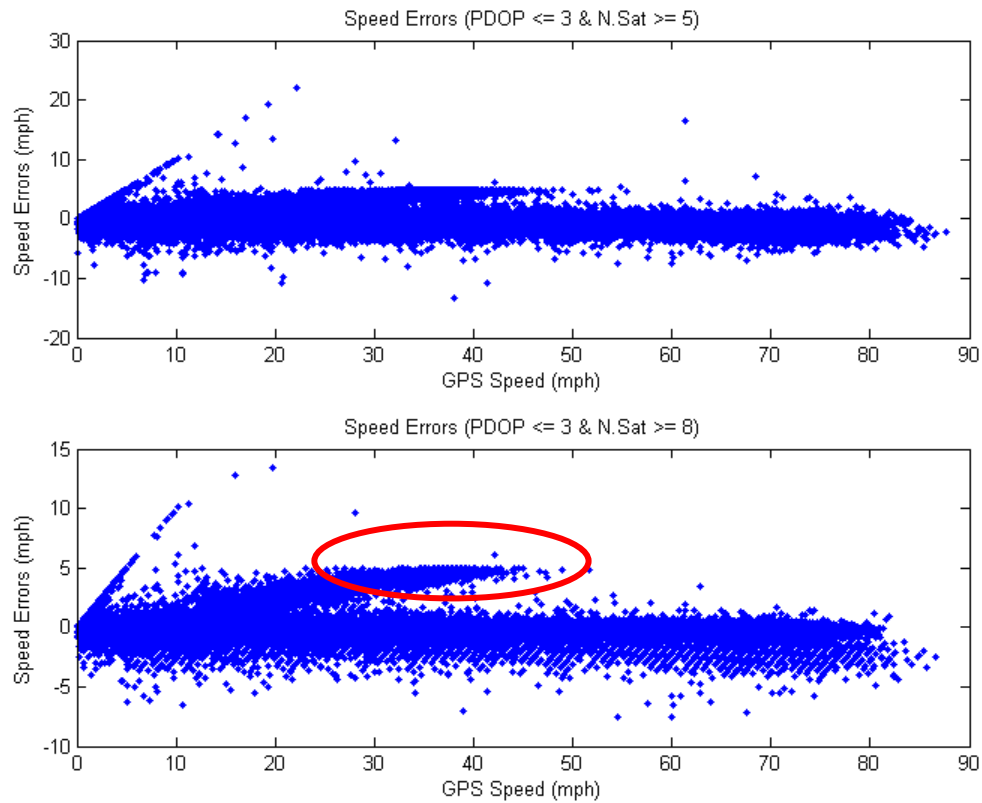


Figure 18 Speed Error Calculated from Un-Calibrated VSS

Jun et al. (2004) developed a process for calibrating the VSS data. Researchers estimated the number of wheel revolutions for a week of data from each of five vehicles within 10 mph bins. Once the VSS data for the five devices was calibrated (434,570 observations), the comparison between VSS and GPS speed showed high correlation between the two sources with R^2 of 0.99742 (see Figure 19).

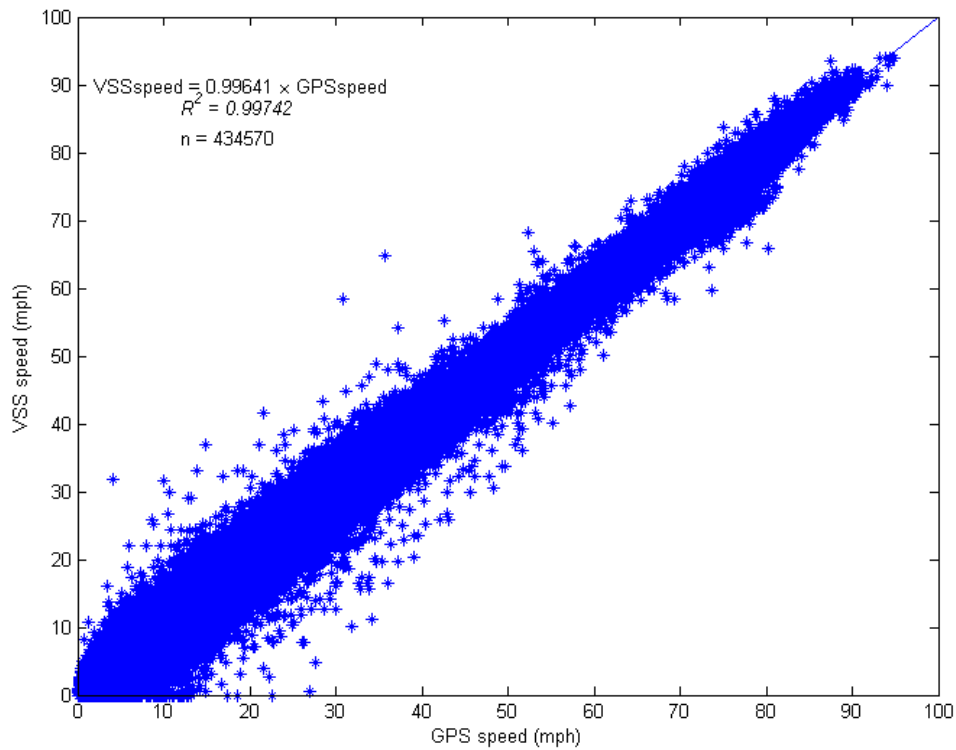


Figure 19 GPS vs VSS Comparison, $R^2 = 0.99742$, $n = 434,570$

Field Test of OBD

Finally, researchers compared speeds obtained from GPS and OBD. The OBD data also had to be calibrated due to the same reasons as the VSS. The OBD data are converted from hexadecimal format provided by the engine computer to miles per hour. In the case of OBD, correction factors were sought to bring the slope of the GPS/OBD regression line closer to 1. Applying a correction factor to the OBD speed does not change the correlation value, R^2 , from the regression model because the correction does not change the linear relationship. However, the correction factor is necessary to achieve appropriate values of the speed error. For this test, 100 trips from 100 vehicles were used. Figure 20 shows the

correction factors applied to each of the 100 OBD speed data streams. Figure 21 shows the results of the regression, again a high correlation is found with R^2 of 0.99626.

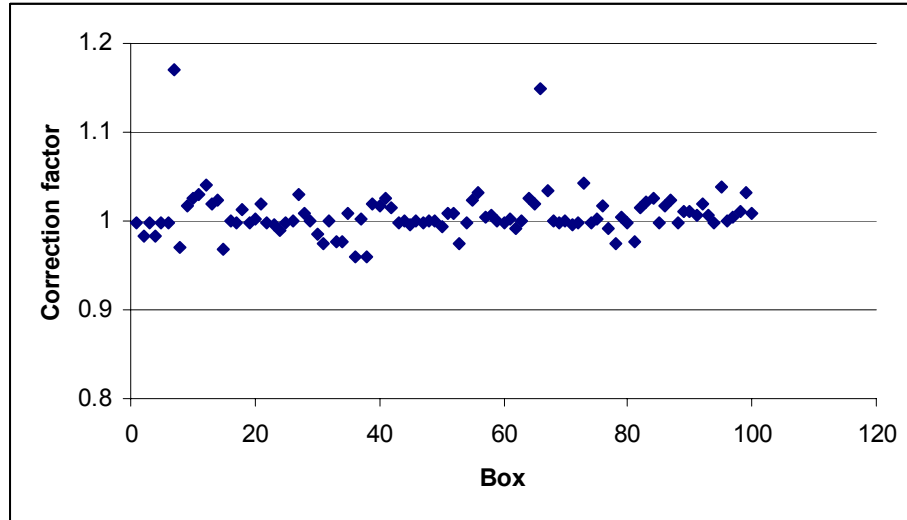


Figure 20 OBD Correction Factors for 100 Vehicles

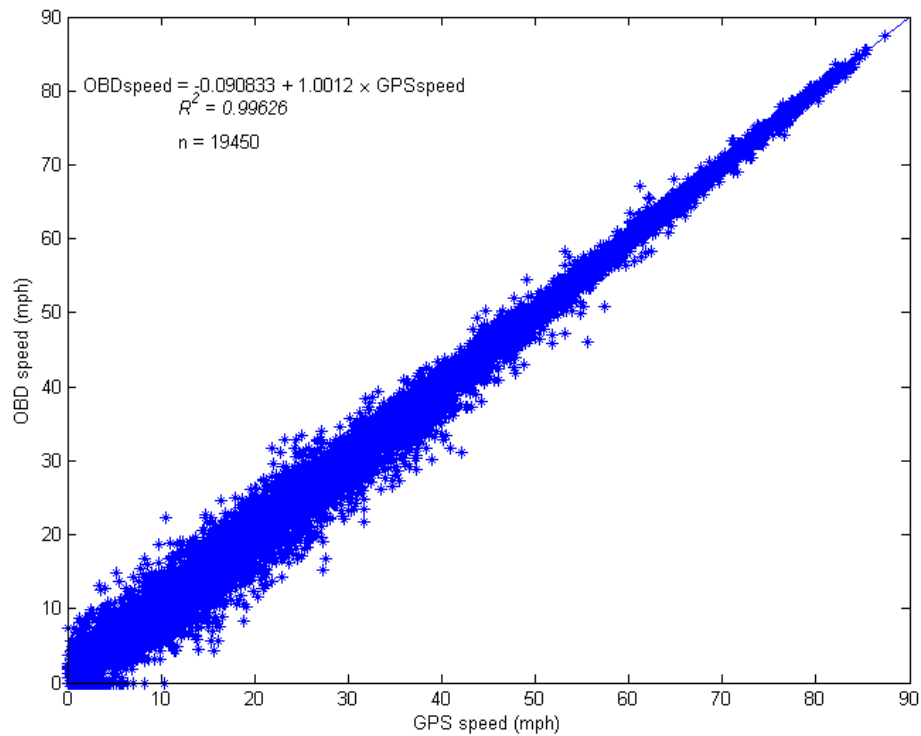


Figure 21 GPS vs OBD Comparison, $R^2 = 0.99626$, $n = 19,450$

Based on the three tests, researchers once again found GPS measured speed to be appropriate for studying driver speeding behavior. Low speeds measured by GPS (considered the most questionable) were within 1 mph of the stationary bench speed 95% of the time. This level of accuracy is sufficient for comparison to speed limits posted in 5 mph ranges. Further, based on the OBD and VSS comparisons, researchers considered all ranges of GPS speed valid. The bench test and field tests using OBD and VSS are some of the most accurate sources of comparison data available. However, there may be additional sources of variance within trips in the VSS speed based on temperature, tire pressure, etc. In comparison, the smoothed GPS speed may be a more accurate source of speed given valid number of satellites and PDOP values. Nonetheless, the speeds are sufficiently accurate for the development of speed profiles for instrumented vehicle behavioral speed studies.

Validation of Posted Speed Limits within the RC File

An equally critical piece of data for calculating percent compliant is that of posted speed limits. Posted speed limits for all roadways in the 13-county Atlanta area were obtained from GDOT within the roadway characteristics file (August 2004). While GDOT area office personnel typically collect most other roadway characteristics (i.e., number of lanes, shoulder type, etc.), the Regional Development Centers (RDC) collect and maintain speed limit data. Subsequently, GDOT incorporates posted speed limit information into the roadway characteristics file. Considering all of the roadway characteristics data, the posted speeds are the most accurate of the data elements. These data are used for speed enforcement programs and must be maintained with reasonable accuracy. The Atlanta

RDC was unable to provide figures on the exact accuracy of the data, so researchers conducted a small validation experiment.

Given the expectation of accuracy, a test was devised to obtain initial accuracy results. Researchers selected three areas within three counties, Cobb, Douglas, and Fulton, for cluster sampling. Cluster sampling techniques allowed minimization of required travel. The Cobb county area included a corridor along GA 120/Roswell Road between Cobb Parkway and Johnson Ferry Road. The Fulton County area included roadways east of I-75 near Georgia Tech campus to Atlanta Road. The Douglas County area included streets in and around Douglasville and just south of I-20 in the same area. Roadways of various posted speed and functional class (primarily arterials, collectors, and locals) were selected for verification from the geographic information system. In total, 87 posted speed limit sections were verified. Table 13 shows the results of the verification by posted speed limit and verification status. Note that researchers conducted prior tests of the accuracy of the posted speed during the database development for the Commute Atlanta program. During this development, researchers drove all freeway segments in the metro area to verify posted speed limit accuracy. Thus, the experiment excluded these types of roadways from focus. Further, posted speed limits on freeway segments continue for many miles and therefore one sampling represents several miles.

The verification test indicated that out of 87 road segments, only 2 were posted incorrectly. One of these was due to the installation of a new school speed limit sign (RC = 35, PSL = 25) near a Montessori school in Douglasville. No explanation is available for the second (RC = 30, PSL = 35). A third situation included a section of roadway that is

listed as having a 35 mph posted speed limit, however, verification was not possible due to a missing sign. Upon a second inspection, construction has begun on the addition of sidewalks along this roadway, and construction workers probably removed the sign in preparation. Overall, this results in a 2% error rate. Given the results of this minimal test, further exploration was deemed unnecessary.

Table 13 Posted Speed Limit Verification Results

Verification Status	Posted Speed Limit (mph)								Total	%
	25	30	35	40	45	55	60	65		
Correct	22	12	29	1	13	4	2	1	84	96.55
Incorrect		1	1						2	2.30
No Sign			1						1	1.15
Total	22	13	31	1	13	4	2	1	87	100.00

Validation of Roadway Network Maps

Researchers obtained copies of the most current roadway network maps for the 13-county Atlanta area from the University of Georgia (UGA) GIS Laboratory. As mentioned previously, UGA is under contract to GDOT to update the roadway network maps and corresponding linkages to the roadway characteristics file. At the time researchers received the map files, the 13-counties were in various stages of completion. Figure 22 shows the development stage for each of the 159 counties in Georgia at the time of receipt. Three main counties (Fulton, Cobb, and Dekalb) were in the worst shape of all 159 counties. GDOT was updating the RC files for these counties to match new network coding including upgrades to dual links for divided roadways. UGA was in the process of

incorporating the RC information into the GIS for three additional counties (Gwinnett, Rockdale, and Douglas). The remaining seven counties (Cherokee, Forsyth, Henry, Clayton, Fayette, Coweta, and Paulding) previously passed the GDOT QA/QC process. Given the objectives and deliverables of the Commute Atlanta project, it was necessary for Georgia Tech researchers to forge ahead and make the necessary changes, amendments, and fixes to the current set of maps to meet deliverable schedules. UGA had originally targeted completion of the project in October 2003. Due to delays in receiving updated RC information from GDOT, UGA currently expects acceptance of the complete set of 159 counties in October 2005.

To understand the difficulties associated with updating the network map files, it is essential to understand the components and processes. To begin, there are three major components of the GIS road network (see Figure 23): the network shape file, the linear measurement, and the attribute table. The network shape file is a linear feature layer within the GIS that depicts the actual shape of the roadway network. The network consists of roadway segments called routes that span from one point to another and can have multiple vertices in between. Layered on top of the network shape file is the linear measurement feature. A measure value represents a relative position along a linear feature. Measures are most commonly used to represent distances. On route networks, the measurement unit is typically the mile-point. The attributes of portions of a measured feature are called events. The location of an event is defined in terms of the measures stored in the linear feature. The event represents occurrences measured between two locations along a route, such as the posted speed limit for a section of roadway. Events are stored in an attribute table. For this project, the attribute table represents the RC file.

DLG-F Basemap Development Status

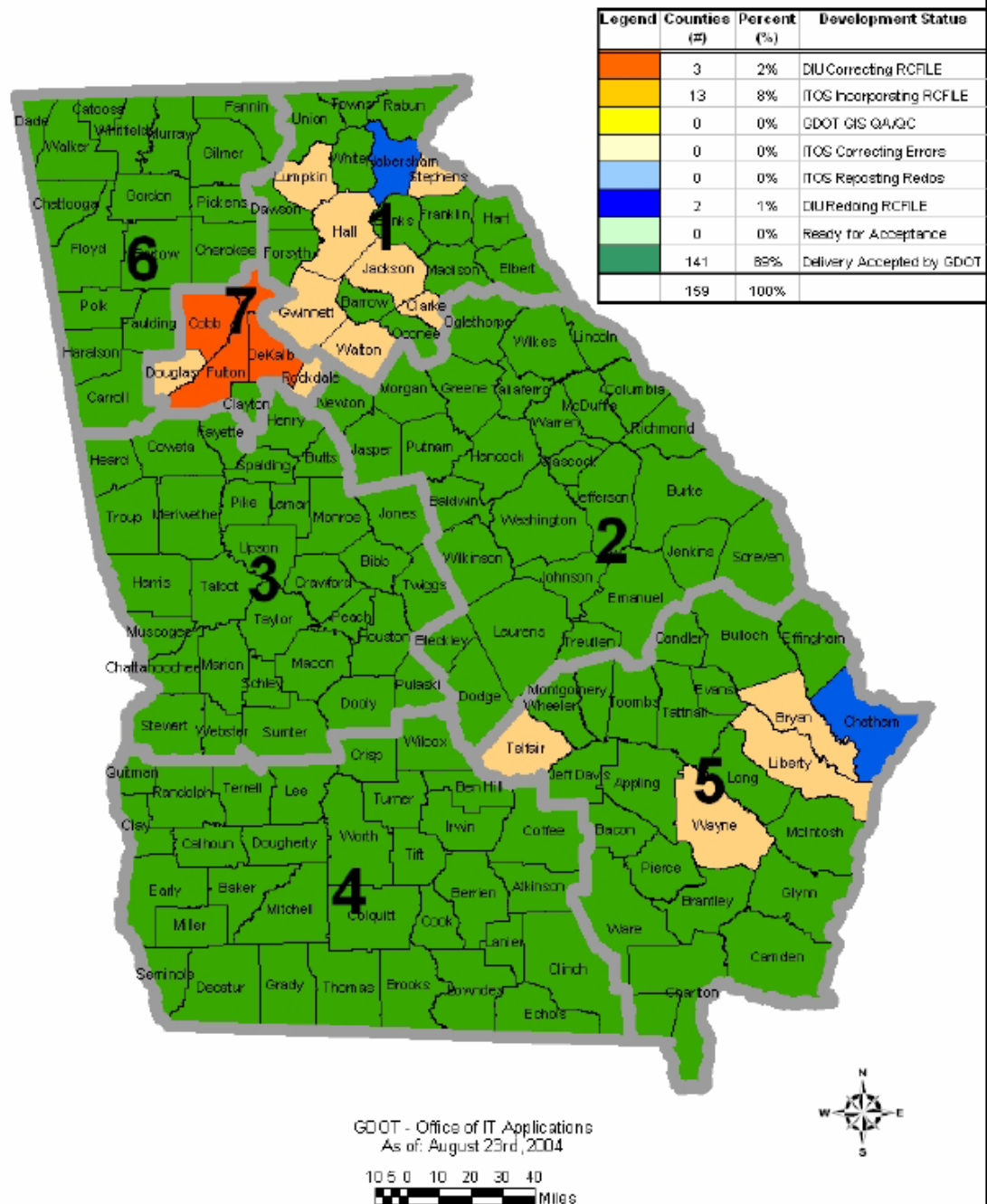


Figure 22 Development Stage for GDOT Roadway Network Maps

There are multiple potential errors associated with the road network GIS including:

- inaccurate shapes - the road is not located at the correct latitude and longitude,
- missing route segments - many newly constructed roadways, especially in residential areas, may not have been added to the map,
- missing measurement values – route shapes exist, but measurement values are unknown, and
- missing route attributes – attributes for road segments may not be included in the current RC file.

Each of these errors affected the processing of trip data for this project, but the majority have been identified and resolved. However, it is unreasonable to expect the road network GIS to be completely accurate. Even after GDOT completes the QA/QC process, it is likely that network errors will still appear due to continual network and attribute changes. Road construction, reconstruction, and rehabilitation are all reasons for these changes. Attributes of roadway width, shoulder type, shoulder width, median type, posted speed, and functional class can all be affected by these changes. Construction and reconstruction can even affect the actual location and shape of the roadway which may not be reflected in the network shape file.

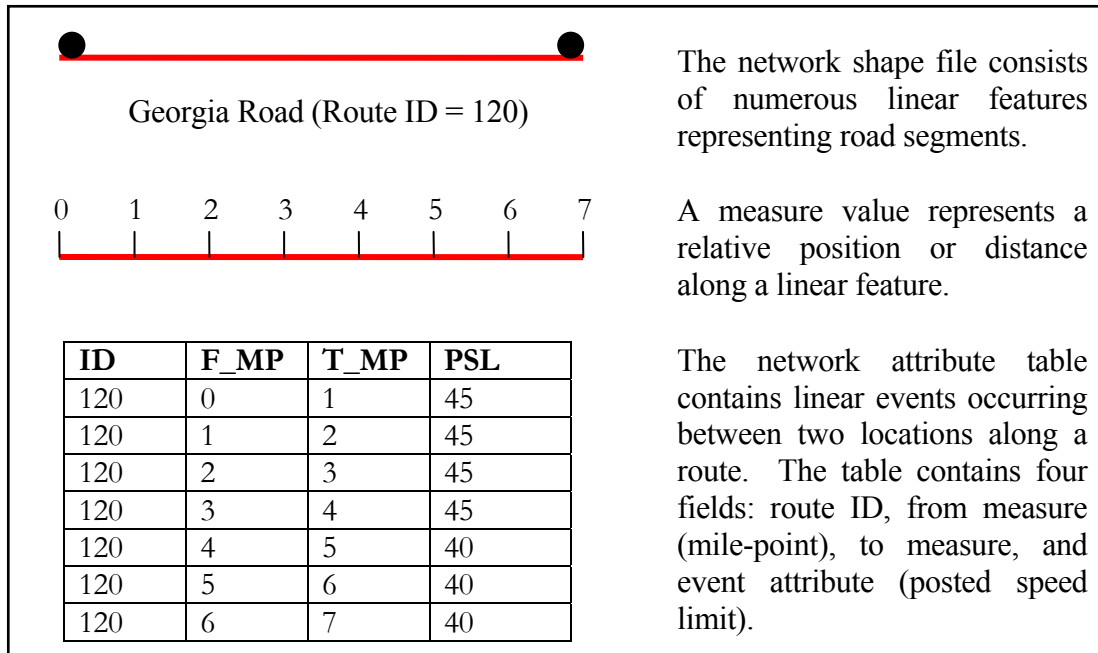


Figure 23 Components of the Network GIS

By far, the largest error impact on this project was the lack of many of the route measurements for Cobb, Fulton, and Dekalb counties. Since GDOT was still updating the RC files for these counties, UGA had not completed the updates of the measure values for all of the roadways. After merging all of the layers in the GIS, the missing measurements impede the merging of the RC file with the network shape file. Initially, researchers believed the problem to be associated with missing RC data, however, after close inspection, the measurement connection was missing. This affected a total of 6,538 routes in the network (see

Figure 24). Among the missing measurements, 1,747 were on freeway, interstate, collector and distributors. Apparent from the figure, a large portion of the eastern half of Interstate 285 and several large arterials were missing data connections. The inability to

match the roadway characteristics data to the network resulted in the inability to match a large portion of speed data in the trip file to the posted speed limit. In fact, researchers were initially only able to match 60% of valid speed data to the posted speeds. The missing GIS connections were causing widespread systematic non-random errors. Part of this error was due to the new coding of dual routes for divided roadways, where only one direction of the roadway was measured.

After several months of manual network coding, and integration of some in-process revisions from UGA, researchers were able to fix the majority of the problems. This was an iterative process. In many cases, the processing of trip data was instrumental in determining the location of problems. Trip summaries resulting in a low percent match between valid observed speeds and posted speeds indicated that routes were missing either measurement values or RC data. From these summaries, researchers were able to go back and look at the individual trips to discern the actual problems. Records missing matched RC data pointed directly to the problem areas. Because drivers typically use the same routes time and again, a route with missing RC information makes a significant impact in the percent of valid data that can be matched at the individual level. Table 14 provides the results of the current network status in terms of the completion rate of matching RC data to the available roadway network shape file. Less than 1% of the segments have missing connections with the RC. Some of the missing RC data is due to the lack of measurement values for short segments near interchanges and other roadway connections (see Figure 25). Although these segments could be reconciled, researchers felt that the added accuracy level did not overcome the required level of labor associated with making these additions. Other segments are missing associated attributes in the actual RC table. These

too could be reconciled through on site roadway inventory, but again, the level of work associated was not worth the expense. The current network GIS produces matching of valid driver speeds to posted speed limits better than 95% of the time on average.

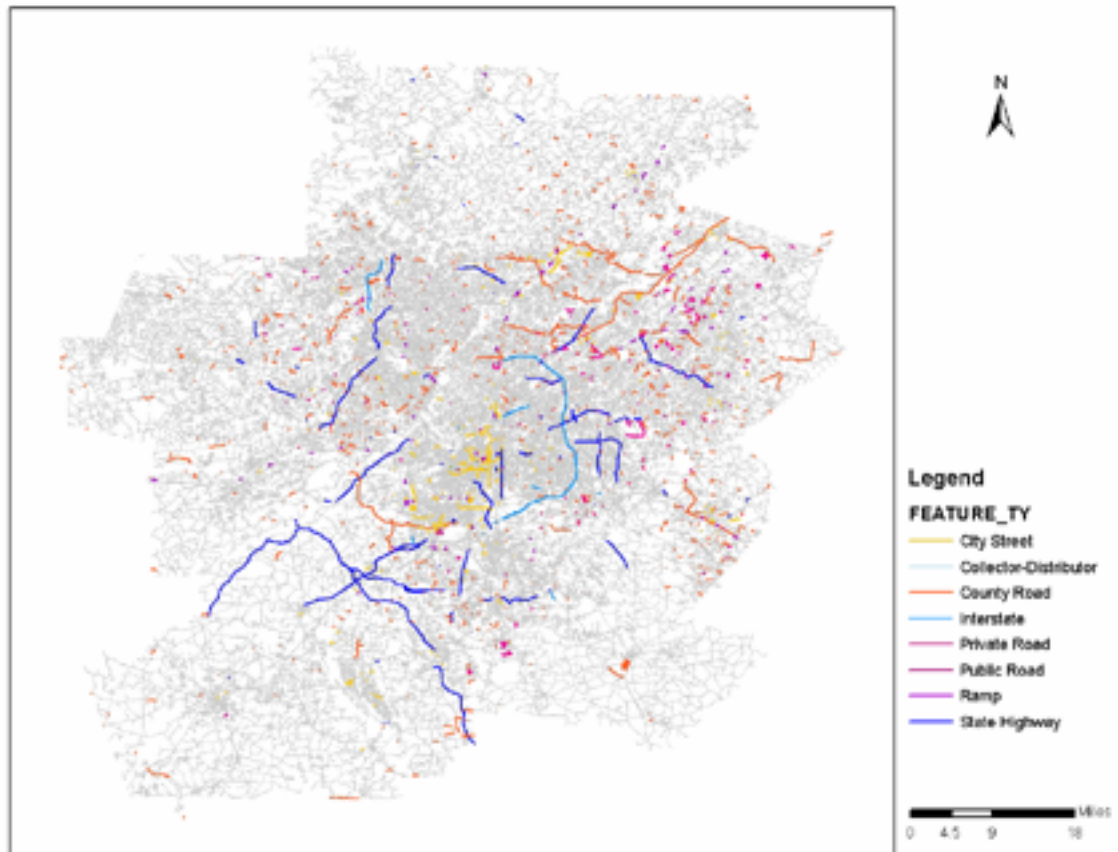


Figure 24 Route Segments with Missing Measure Values

Table 14 Final Tally of Route Sections with Missing RC Information

<i>GDOT Roadway Type</i>	<i>Total Count</i>	<i>Total Length (miles)</i>	<i>Count Without RC</i>	<i>Length Without RC (miles)</i>	<i>Percent Without RC</i>
1: state route	9,362	1,803.3	72	12.2	0.007
2: county route	88,939	12,961.0	427	62.5	0.005
3: city route	33,274	3,478.7	106	12.6	0.004
5: unofficial route	5	0.2	0	0.0	0.000
6: ramp/interchange	1,619	245.1	195	28.6	0.117
7: private road	572	56.9	1	0.1	0.001
8: public road	4,677	467.0	87	13.4	0.029
9: collector road	327	40.7	1	0.2	0.004
D: freeway uncoded direction	1,759	525.7	150	18.9	0.036
Total	140,534	19,578.7	1,039	148.5	0.008

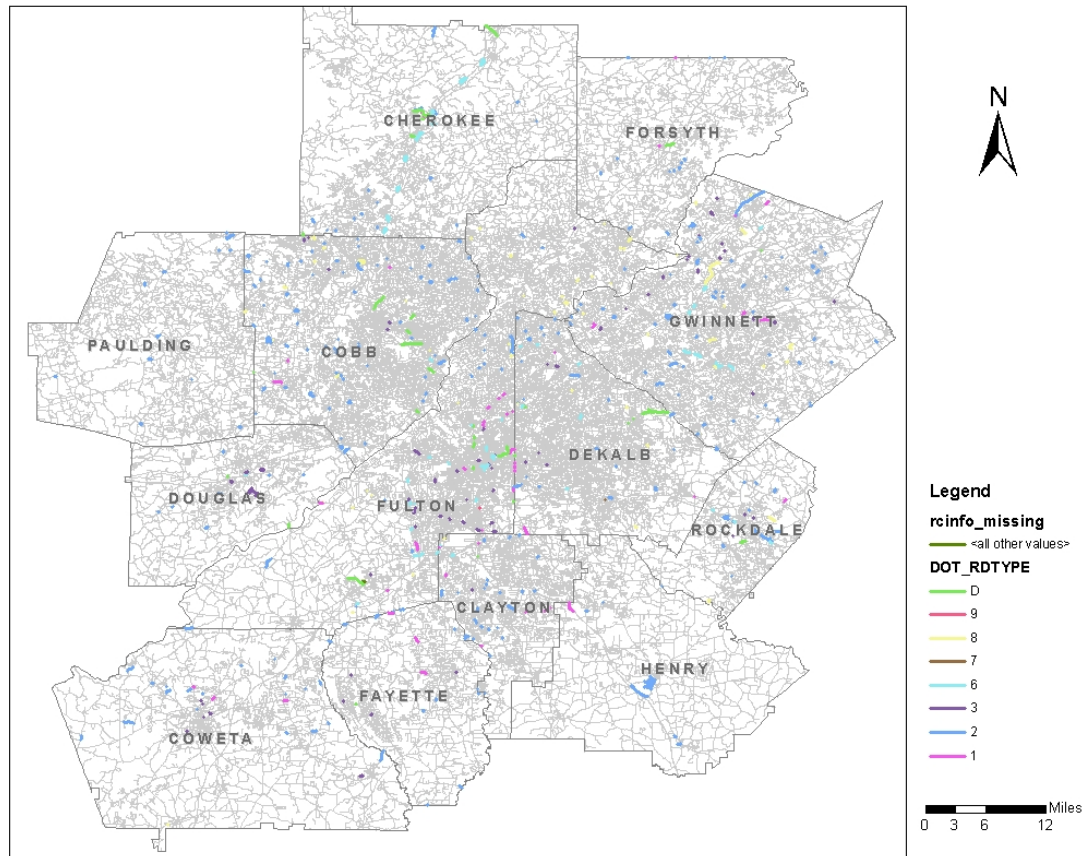


Figure 25 Final Network Segments Missing RC Information

Driver Identification

To develop a speeding profile for the individual driver, it is essential to know with some certainty the identity of the driver of the vehicle. The best way to achieve this is to have a positive identification component of the in-vehicle equipment. This could take many forms including unique keys, keypad with code, radio-frequency identification (RFID), card swipe, driver camera, or fingerprint reader. During equipment development, researchers even investigated a device that matched the imprint of the drivers hind area as he/she sat on a sensor laid over the seat. The problem with many of these devices was the cost. Aside from the cost, other devices were intrusive and caused the driver to interact and acknowledge the presence of the system prior to every trip. Researchers were concerned with providing constant reminders of the equipment, fearing that the reminders might cause the participants to change their driving behavior. A transparent system, on the other hand, would allow drivers to revert to normal driving once the system had been in place for a while. Given the number of devices retrieved from vehicles that have been sold or traded with the devices still in the vehicle, researchers believe that the transparency of the system has been effective.

However, without a positive identification system, researchers must rely on stated and revealed reports of vehicle sharing. With multiple opportunities for participants to report vehicle sharing, researchers are confident, that the majority of the vehicle sharing can be identified and these vehicles removed from subsequent data analysis for driver profile development. Participants have had four opportunities to report vehicle sharing: during the recruitment interview, during the summer travel diary interview, during the spring travel diary interview, and in the year-end mail-out/mail-back participant survey.

During the recruitment process, households provide information on each vehicle owned or leased by the household. A primary driver is assigned to each vehicle if one exists. Further, recruiters ask households whether the vehicle is shared among other drivers in the household. If so, the vehicle is coded as shared in the vehicle table.

The travel diary interviews are a secondary source for identifying vehicle sharing. Each household member over the age of 5 indicates the number of trips made for each of two consecutive assigned travel days. Additional interview questions inquire about the mode (drove, walked, rode bike, rode bus, etc.) for each trip, and for responses indicating that the person drove on a particular trip, participants are asked to report the vehicle used to make the trip. A query of trips by mode, vehicle, and driver provides information on revealed vehicle sharing over the two travel diary days. Household vehicles with two or more revealed drivers over the two-day period are considered to be shared vehicles.

The last source of information for vehicle sharing is the initial year-end participant survey. This survey was primarily concerned with collecting updated household information for recruitment into the pricing experiments in year two. Researchers dedicated one page of the survey to identification of primary and secondary drivers for each household vehicle. Here, the participants were asked to list each household vehicle, provide the primary driver of the vehicle, any secondary drivers, and the estimated amount of driving by each driver. The majority of the vehicle sharing identified in the earlier recruitment and travel diary interviews repeated here.

One trend appeared in the participant surveys, which was not apparent earlier. The majority of households with two adults (spouse/partner relationship) typically identified

one household vehicle as shared minimally by both adults. For example, the male of the household may drive a pick-up truck as the primary and sole driver. However, within the same family, the female may be the primary driver of a late model sedan used also for family outings, which is subsequently driven a small percentage (typically noted between 1-5%) by the male. Due to the widespread tendency of this occurrence, these vehicles were not considered shared, unless the shared percentage was identified as greater than 10%. Further research is planned to discern the actual magnitude of the vehicle sharing through study of acceleration patterns as well as additional survey questions and participant interviews.

For this research, a conservative approach was taken in terms of vehicle sharing. All indications of vehicle sharing except that noted as minimal (1-5%) between two adults within the same household eliminated those vehicles from consideration in the study of driver speeding. Unless the vehicle has only one reported driver, little confidence can be placed in the analysis of trip characteristics and driver demographics on the choice of speed and the development of the driver speeding profile.

Filter # 1
Remove all vehicles identified as having more than one driver
(with the exception of vehicles shared 5% or less by spouses)

GPS Trip File Processing

The processing of GPS trip files is the most time-consuming procedure involved with this research. For each week of trip files recorded by the instrumented vehicle fleet, it

takes better than two-weeks to fully process and summarize the data contained in the files on one computer. The trip file processing includes 11 steps:

- Select files from archives
- Unzip files
- Run point-in-polygon test to determine file status
- Map-match GPS records using route method
- Map-match GPS records using buffer method
- Clean records matched with buffer method
- Merge data from two map-matching methods
- Summarize trip files into trip table
- Summarize trip files into speed-acceleration frequency distribution plots (Watson plots)
- Summarize acceleration data
- Merge trip and Watson summaries with driver socio-demographic data

The following sections describe each of these processes in brief, including information regarding any filters associated with the individual processing steps.

Select Files from Archives

This is one of several steps that may sound trivial, but is rather involved due to the intricacies of the data collection process and database structures. Because this research is dealing with the general public and a naturalistic driving experiment, there are logistics involved that are typically not included in experimental studies. For example, each household vehicle has a data collection device installed. When the household decides to sell or trade a vehicle, the research team must remove the device and install it in the new

vehicle. In this instance, the characteristics of the vehicle have changed and must be reflected in the analysis. Vehicle purchases often induce changes in primary driver, or the addition of a new driver in the household. These too must be reflected in the analysis. Further, given that the in-vehicle equipment was in early deployment stages upon first installation, there have been software updates that have required equipment exchanges. Each time this occurs, all of the elements (household, vehicle, and driver) associated with the data from that box change. If the chosen study period spans multiple months, these changes can be burdensome to track. Ultimately, researchers must assure that they have associated the correct demographic information to each individual trip file.

For this study, there were additional considerations for selecting the files for analysis. These considerations included installation schedules, weather, time-changes, and holiday/school schedules. To increase the potential availability of the sample, researchers considered only the period occurring after February 2004 since the installation of equipment ran into January 2004. The weather was the next consideration. The effects of rain on driver speed choice have been reported previously in research and summarized by Prevedouros in 2003. Effects vary significantly and range from none to a 19 mph reduction. Regardless, researchers tried to choose a period with minimal rainfall activity. Researchers collected daily precipitation data from the National Oceanographic and Atmospheric Administration (NOAA) from 16 weather stations across the 13-county area for a period of three months (February, March, and April of 2004). February showed several periods of heavy rain, as did April. Precipitation in March was minimal, but occurred on several dates. The highest rainfall amounts were 0.63 inches on March 30,

2004 and 0.29 inches on March 6, 2004 (see Figure 26). Two full weeks fall between these dates and were considered potential candidates for analysis.

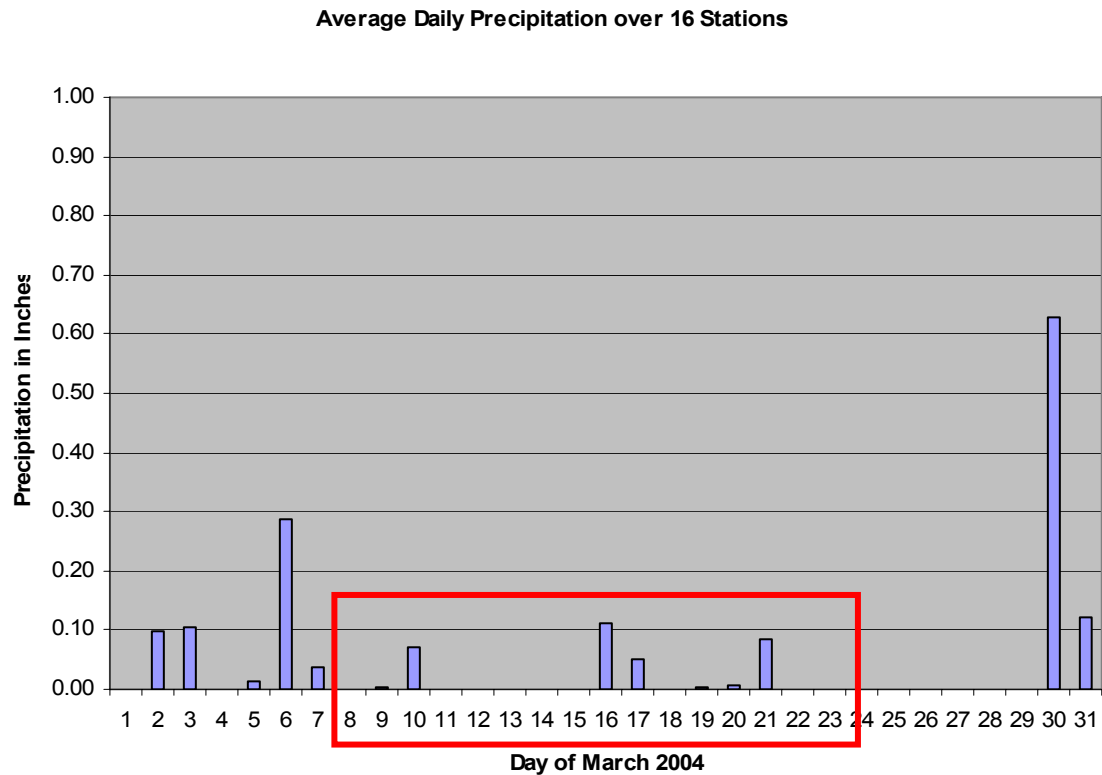


Figure 26 Average Precipitation for Atlanta, GA from March 2004

Two other conditions known to affect travel behavior are holidays and the change to and from daylight savings time. The change to daylight savings occurred on April 4, 2004. Additionally, the majority of Atlanta public schools were on spring break holiday the week of April 5-9, 2004. Given these two occurrences, the first two weeks of April

were excluded from consideration. Based on all of the considerations, researchers settled on the period of March 8-23, 2004 for the analysis period.

Unzip Files

The trip files located in the archives are encoded and zipped for privacy protection and to reduce storage requirements. However, to process the files, they must first be moved to the processing space and unzipped. Again, this does not seem to be a difficult task, but does require some diligence. The files are grouped in archives by download batch date. Every night, a batch of in-vehicle devices is set to report. If a device is not in the cellular service area or in a good coverage area, the box will not report until the next scheduled download period. Therefore, multiple archives must be searched to obtain all occurrences of trip reporting for the full sample for the chosen time-period.

Run Point-in-Polygon Test

The GIS only includes speed limit coverage for the 13-county area. Therefore, travel outside of the area are not matched with roadway characteristics, which prevents the complete calculation of exposure for some drivers within the Commute Atlanta program. The first real step in processing the trip files is running the point-in-polygon test to determine the status of every record in each trip file. The point-in-polygon test determines whether valid GPS records lie within or outside of the 13-county study area (see Figure 27). Since one of the main objectives of this research is to develop a framework for assessing safe behavior performance using behavioral safety techniques to count unsafe behaviors (speeding), if measured speeds cannot be matched to posted speed limits, speeding behavior cannot be discerned.

If a large portion of the drivers behavior performance occurs outside of the 13-county area, little can be determined about that drivers overall performance. Some drivers live on the fringe of the 13-county area and a large percent of their daily travel occurs outside the study area (see Figure 28). This is different from the situation where a person lives well within the area and makes a long trip out of the area for a vacation (see Figure 29). Out of the area travel can be evaluated in terms of percent of vehicle miles traveled, number of trips, and percent of observations occurring outside of the area. All were scrutinized and have an impact on which vehicles to include in the analysis. However, the percent of observations allowed the most objective analysis of the magnitude of missing exposure. Drivers with approximately half of observations out of the area were typically on long travel, such as a vacation. Drivers with 20-25% of observations out of the area typically reside on the metro fringe. To obtain the clearest picture of safe driving performance, drivers with more than 5% of valid speed observations outside of the 13-county area were excluded from analysis. While this filter would best be served by including only drivers with 100% of travel inside the area, this is an unrealistic expectation. Drivers must leave the area on occasion, and therefore, minimal exceptions were included. In future studies, the limitations of the geographic database may not require such a filter. .

Initial reviews of the effects of this filter on the relatively small sample of eligible young drivers (age 15-24) prompted an exception to the filter. A secondary review of the out of area travel showed this group to be over-represented. The expected reason for this was the college spring break schedule, which had not been included in the holiday impact list.

Filter # 2
Remove all vehicles with less than 95% of travel in 13-county area
(Excepting the 15-24 age group due to spring break travel)

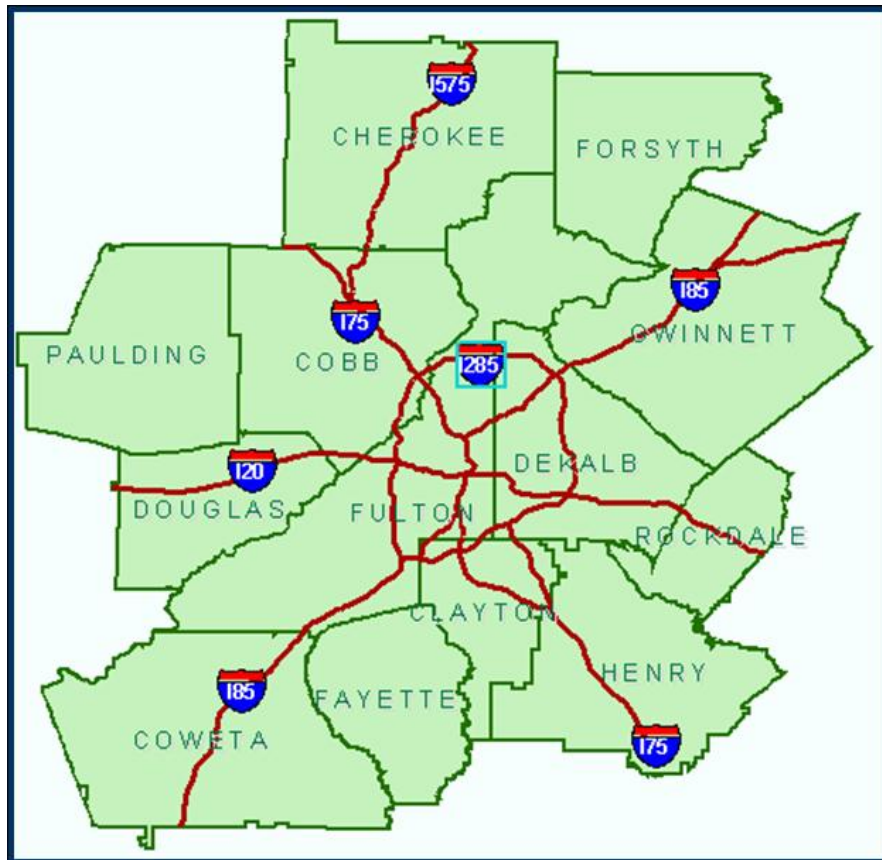


Figure 27 The 13-County Metropolitan Atlanta Study Area



Figure 28 Repeated Out of AreaTravel



Figure 29 One Long Trip Out of Area

In addition to determining whether points are in or out of the area, the point-in-polygon test also serves as an accounting method for determining number of valid GPS points in each trip file. Valid GPS points are those based on signals from 4 or more satellites, and with a positional dilution of precision (PDOP) between 1 and 8. The generated output of the process is a simple table that provides each trip filename, and associated statistics for the number of valid points in the area, number of valid points out of the area, and the total number of points in the file from which invalid points can be calculated.

Two filters are derived from this table. One filter searches for devices reporting trip files with no valid GPS points. There are several reasons that a device may not report valid GPS data including:

- Equipment defect – broken/defective GPS receiver component
- Box tampering – removed/cut GPS antenna connection
- Communications difficulties – trip files not properly uploaded to server

Each of these reasons for not reporting GPS data also signal a need for equipment maintenance.

<p style="text-align: center;"><i>Filter # 3</i> <i>Remove all vehicles not reporting valid GPS data</i></p>
--

The second filter is related to the last and searches for devices reporting large percentages of invalid GPS data. This occurrence also has several possible causes:

- Ineffective antenna location – signal is partially blocked and causes intermittent signal loss
- Geographic area – drivers general travel area may not be conducive to GPS data collection (such as urban canyon, heavy tree canopy, etc.)
- Equipment malfunction

This filter is less straight forward, because there has to be some subjective judgement on the constitution of enough valid GPS. However, the filter is used in this case was based on obvious cases where less than half of the records are valid. The majority of driver trip data had approximately 75% or more valid GPS records. There was a substantial division between groups with valid and invalid data.

Filter # 4
Remove all vehicles where less than 50% of GPS data are valid

Map-match with Route Method

Researchers used two map-matching methods in combination to process the GPS data for this research. The first method was developed specifically for the Commute Atlanta program, and is focused on selecting specific links of travel and developing routes that can be matched to one another for alternative route analysis. This method is sophisticated and produces most the appropriate matches between the GPS data and the network attributes; however, the process does not work when there are map or GPS data errors. One instance in which the route map-matching process does not work is when the process encounters locations of disconnected roadway network segments. This error can occur at locations where to network segments have been joined together, such as a connections of roadways at county lines. In this case, the route terminates at the end of the

link. Because the GPS points within a specified distance of the route are matched to the assigned route, GPS points beyond the end of the link where the map-matching algorithm terminated are not matched to route with associated roadway characteristics.

A second problem arises when there are extended periods of GPS signal loss. The map-matching process uses the actual GPS points to develop intermittent stop locations for locating the route links. When there are extended periods of signal outage, the selected stops can be too far apart to find an appropriate route between them. Again, the route is terminated at the point where the route generation fails, and GPS points beyond this are not associated with roadway characteristics. Figure 30 shows the basic steps in using the route map-matching process. The ultimate outcome of such a process is to write a roadway characteristics link ID and other characteristics such as the posted speed limit and functional class to each valid GPS record in the trip file.

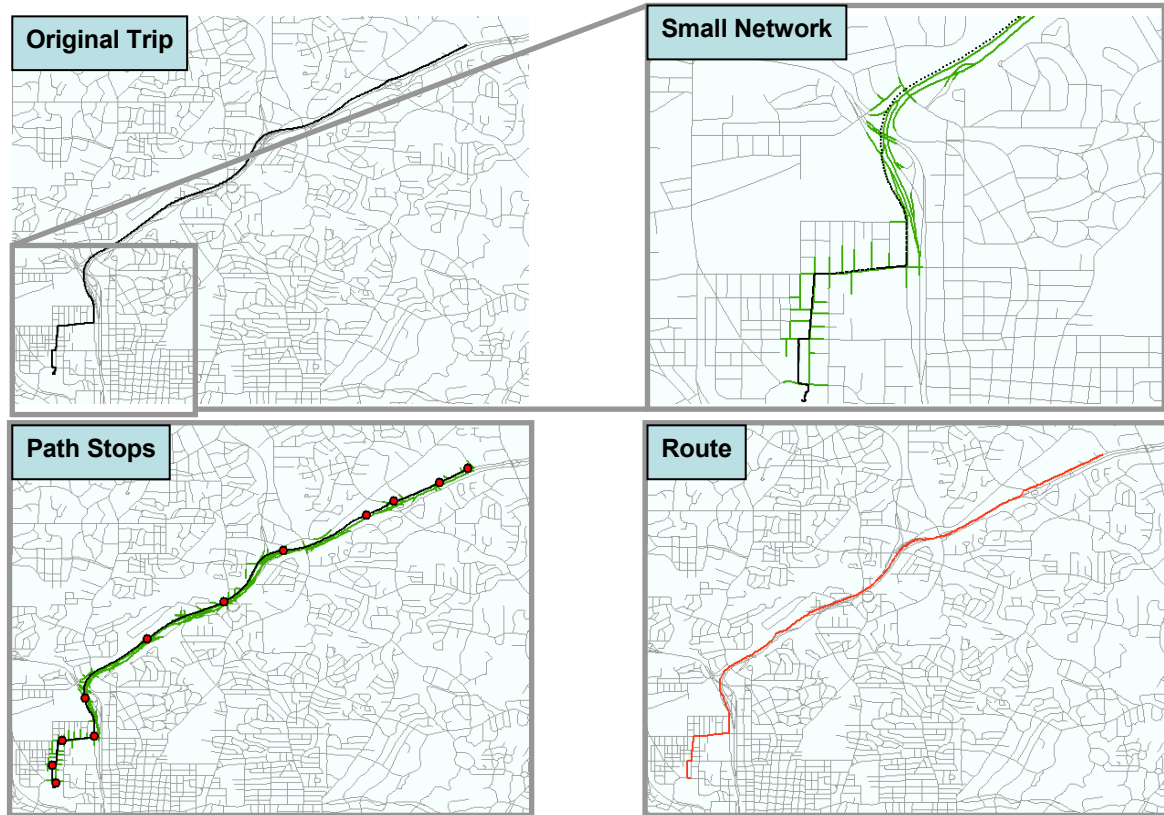


Figure 30 Route Map-matching Method

Map-match with Buffer Method

Due to the difficulties associated with using the route map-matching method imperfect data and maps, a secondary method was devised to match the remaining GPS points with their respective network segments. For this research, it was more important to match all valid data than to have complete routes. Further development of the route map-matching method is ongoing, but the alternative two-method approach is sufficient for this research. The buffer method works in a slightly different manner from the first, and is much simpler in design. Essentially, the process selects a small network area surrounding the GPS points for the specific trip. A 100 foot buffer is drawn around the small network,

and all points falling within this area are joined to the closest network link. This method matches all GPS points within a reasonable distance of the roadway centerline to a link (see Figure 31).

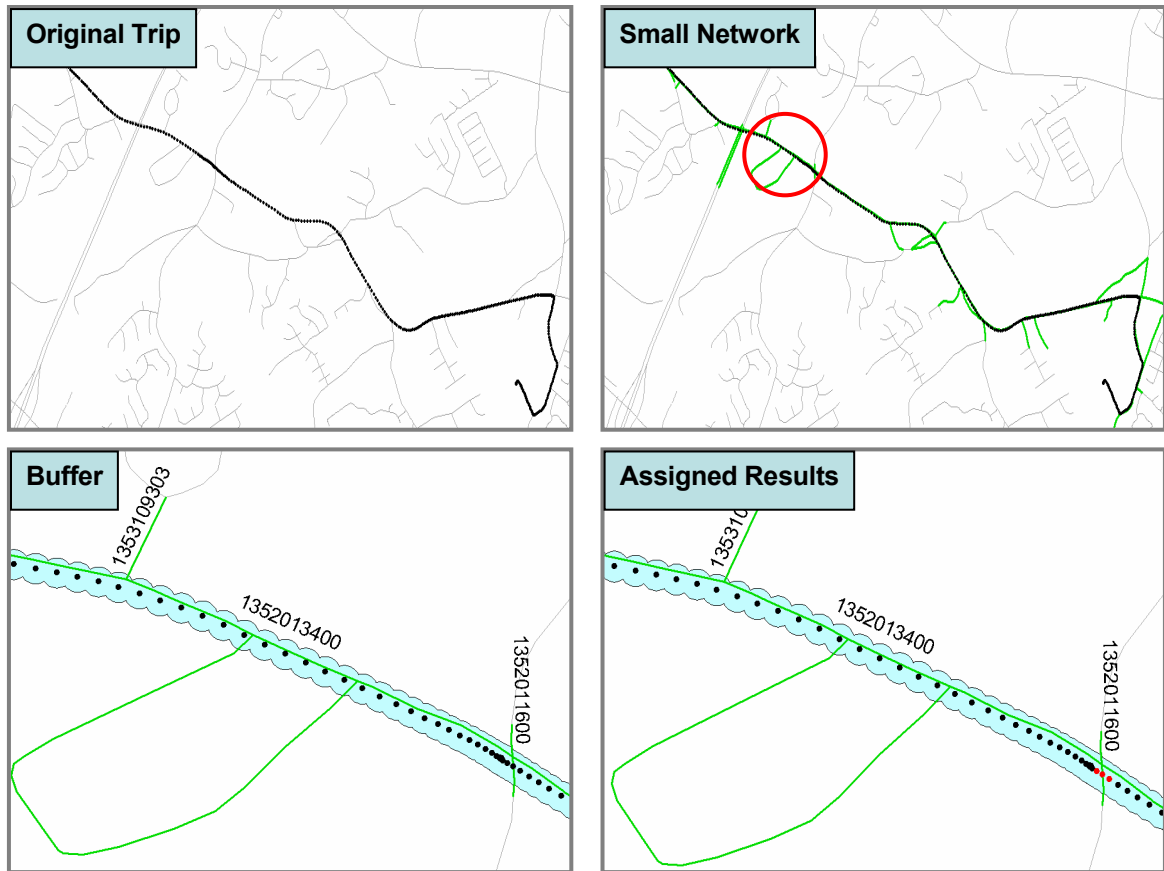


Figure 31 Buffer Map-matching Method

Clean Records Matched with Buffer Method

Potential miss-matches offset the simplicity of the buffer method. Although the buffer method appears to be simple to apply, errors are possible due to rules associated with determining the closest link. As the driver traverses the roadway network, GPS points are recorded at a frequency of 1-Hz. In general, 95% of these data fall within 15 feet of the actual location and will be closest to the network links actually traversed. However, at

roadway junctions, one or more instances may be associated with the cross-street (see Figure 32). Researchers developed a Perl script to sort through each record looking at several records in front and behind. When a record is identified with a link id different from the ones prior and after, the id is changed to be equal to prior link. Although mismatched data is rare, it must be cleaned so that additional error is not introduced into the data set.

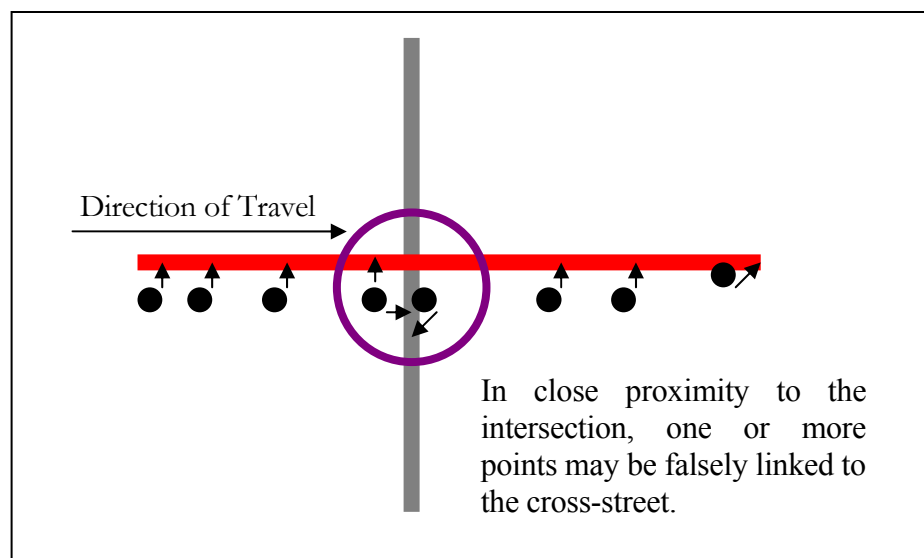


Figure 32 Miss-match from Buffer Method

Merge Data from Two Map-matching Methods

Once the GPS data in the trip files have been paired with roadway characteristics using both the route and buffer method, the records derived from each method have to be merged to form a complete set of matched data. Match characteristics derived from the route method are the primary source. Valid records without match characteristics in the route matched file are then merged with the match data from the cleaned buffer method.

The result is a set of records where all valid records have been matched to RC unless no RC information exists (less than 1% of links).

During data analysis, several issues were uncovered in terms of default posted speed limit values and coding of functional classification within the GIS. The default posted speed limit for roadway sections where the actual speed limit is unknown are coded at 55 mph. Figure 33 shows the query of road segments with speed limits of 55 mph and classification of local road. Two errors were immediately detected. The first is that nearly every interchange around town has a functional classification of local road. The second error involves random segments of local (mainly residential) areas with coded speed limits of 55 mph. Both of these errors are circled in Figure 33. Figure 34 provides a more detailed view of the random occurrences of this coding structure.

The classification issue with the interchange ramps was magnified by a secondary problem encountered during measurement of driver speeding behavior. Many of the cloverleaf and partial cloverleaf ramps (see Figure 35) are posted at 25, 30, 35, and 40 mph speed limits. Upon exiting the freeway network, the posted speed immediately changes to the lower value causing very large differences between the driver speed and the posted speed. Unless removed from the data, these large differentials on ramps cause skewed distributions of speeding behavior. These problems were resolved by removing the roadway characteristics from all data matched to ramps using a value in the characteristic attribute file, 'R-type' or roadway type. Values of roadway type of 6, ramp, were removed from the matched records while the original record attributes were maintained. The

removal did not affect the ability to sum this distance into the total exposure calculation or monitor total trip duration.

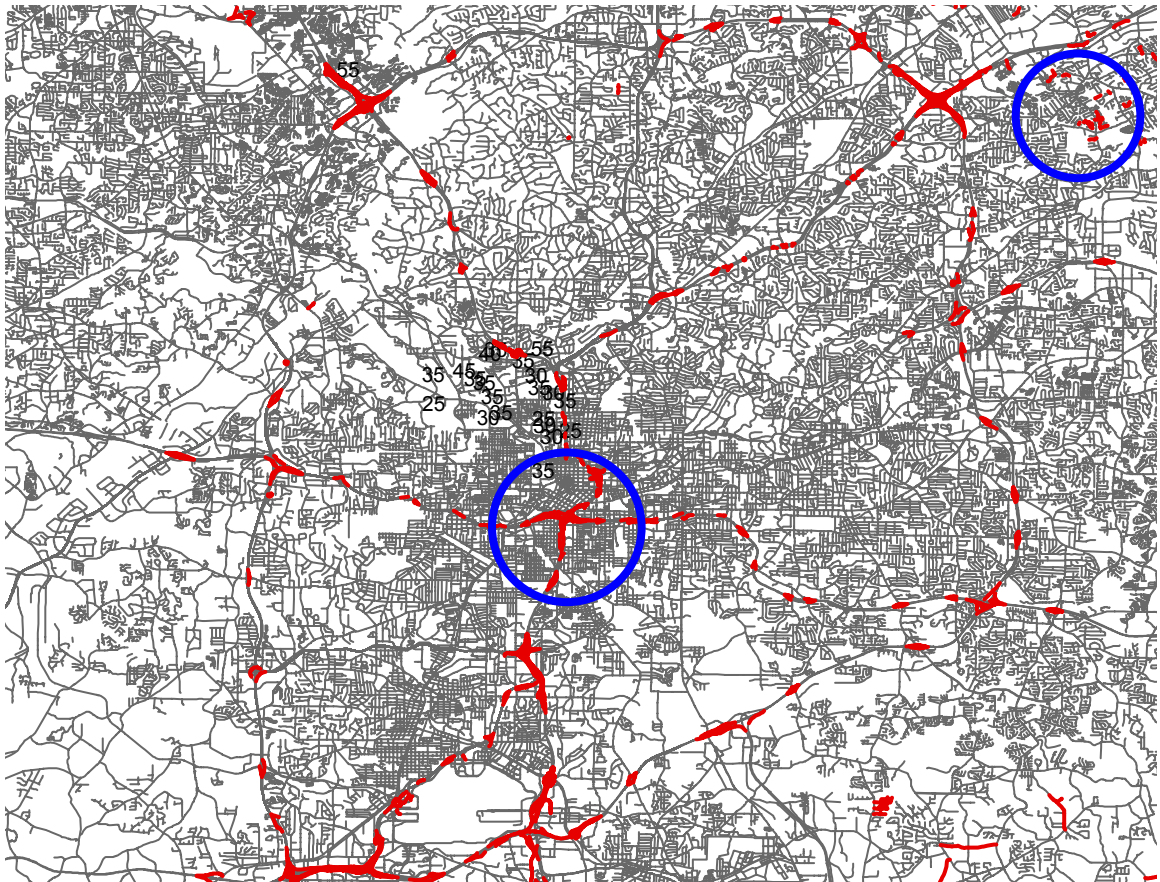


Figure 33 Road Segments with 55 mph PSL and Local Classification

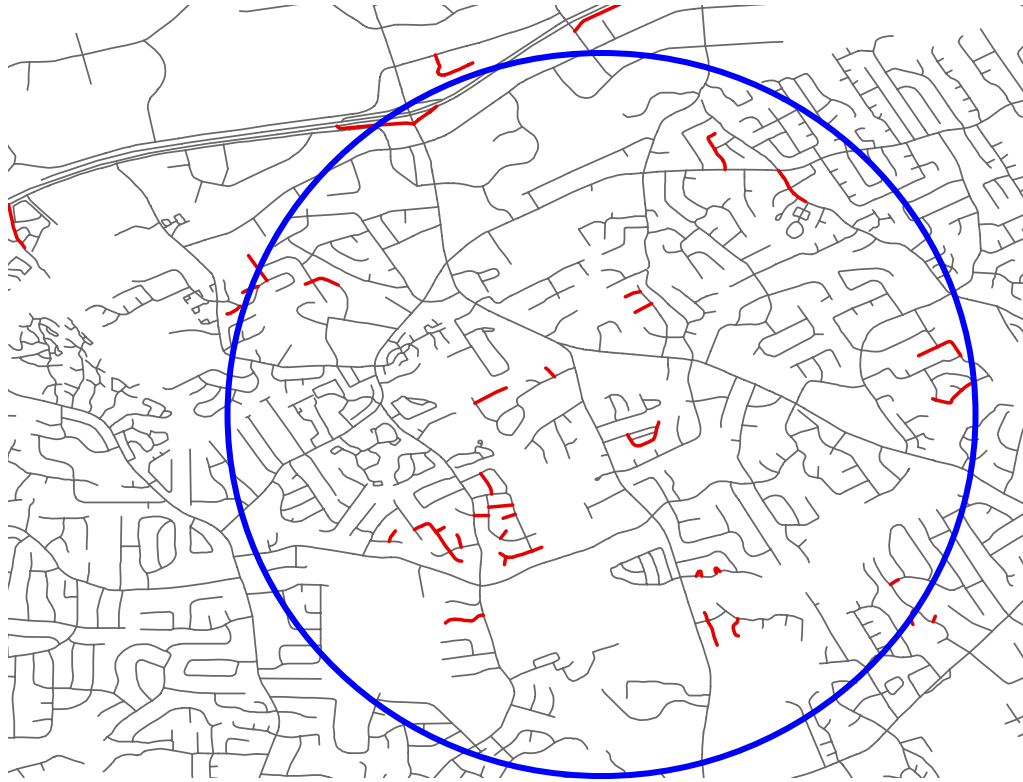


Figure 34 Detail of Random 55 mph PSL on Local Classification

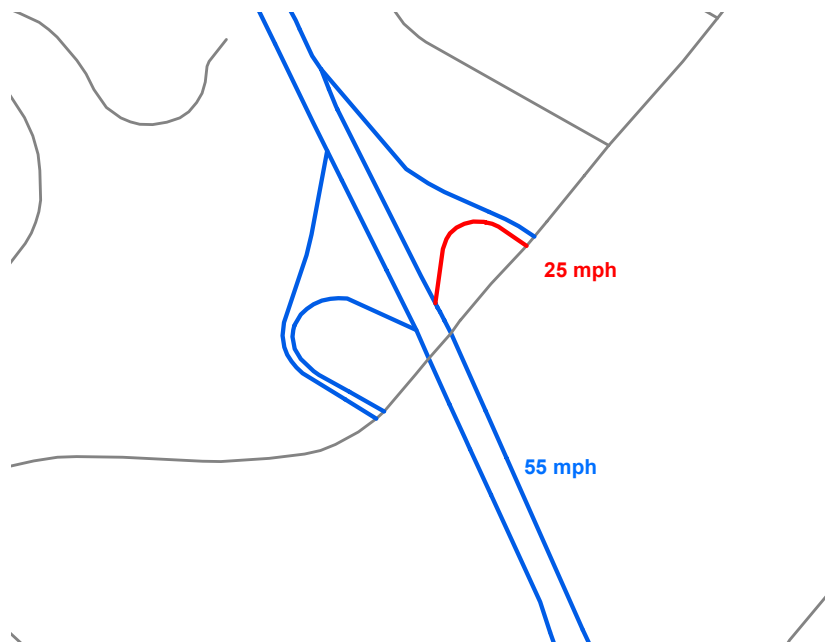


Figure 35 Cloverleaf Ramp with 25 mph Posted Speed Limit

Summarize Trip Files into Trip Table

For the two weeks in March, there are 31,408 trip files containing 30,540,525 GPS records for the full Commute Atlanta sample. On average, each trip file contains 972 GPS records. To more efficiently analyze the information contained in all the files and records within the files, the trip files are summarized into one large trip table. The trip table contains one record for each trip file. Data summarized for each trip include date/time of trip, trip length (miles), trip duration (minutes), average trip speed, total number of records, total number of valid GPS records, valid records with speeds greater than 5 mph, valid records with speeds greater than 5 mph successfully matched with RC information, number of records where speed is greater than the posted speed limit, number of records where speed is more than 10 mph above the posted speed limit, number of records where speed is more than 15 mph above the posted speed limit, etc. Additional tables summarize trip data by posted speed limit and functional class.

From the trip table, researchers can begin to analyze trip data in terms of percent of valid data versus the percent of valid data matched to RC, and total time of movement. At this stage, a low percent match between measured speeds and RC indicates GDOT map data errors along a regularly traveled arterial or lower classification route at the individual level that will not be repaired. Approximately 22 drivers had less than 80% of valid records matched with RC information. Upon close inspection of the trips, several standard corridors were either missing the network link, or the RC file did not contain information for the link. Filter 5 removes these vehicles from the study.

Filter # 5
Remove all vehicles with low match percentages (<80% matched)

The last filter is associated with the total movement time. Researchers eliminated vehicles with a low amount of actual driving time over the two week period (<30 minutes). Minimal amounts of driving may be associated with rare use of the vehicle, driver out of town, or equipment malfunctions. By looking at the trips files generated from the vehicle for other time-periods, some of these reasons may be removed from question.

Filter # 6
Remove all vehicles with minimal amounts of travel (<30 minutes)

Summarize Trip Files into Watson Plots

A Watson plot is a summary of the frequency of speed and acceleration activity within specified ranges. For this study, researchers defined Watson plots grouped by posted speed limit for each driver. Therefore, extreme acceleration and deceleration activity can be measured in relation to speeding behavior. Figure 36 is an example of a Watson plot. The lower left axis gives acceleration activity in 0.5 mph/s bins ranging from -8 mph/s to +8 mph/s. The lower right axis provides speed activity in 5 mph bins ranging from 0 mph to 100 mph. The vertical axis indicates the percent of activity within each bin. To keep from having a double center peak separating 0 to 0.5 mph/s and 0 to -0.5 mph/s, these two bins have been merged.

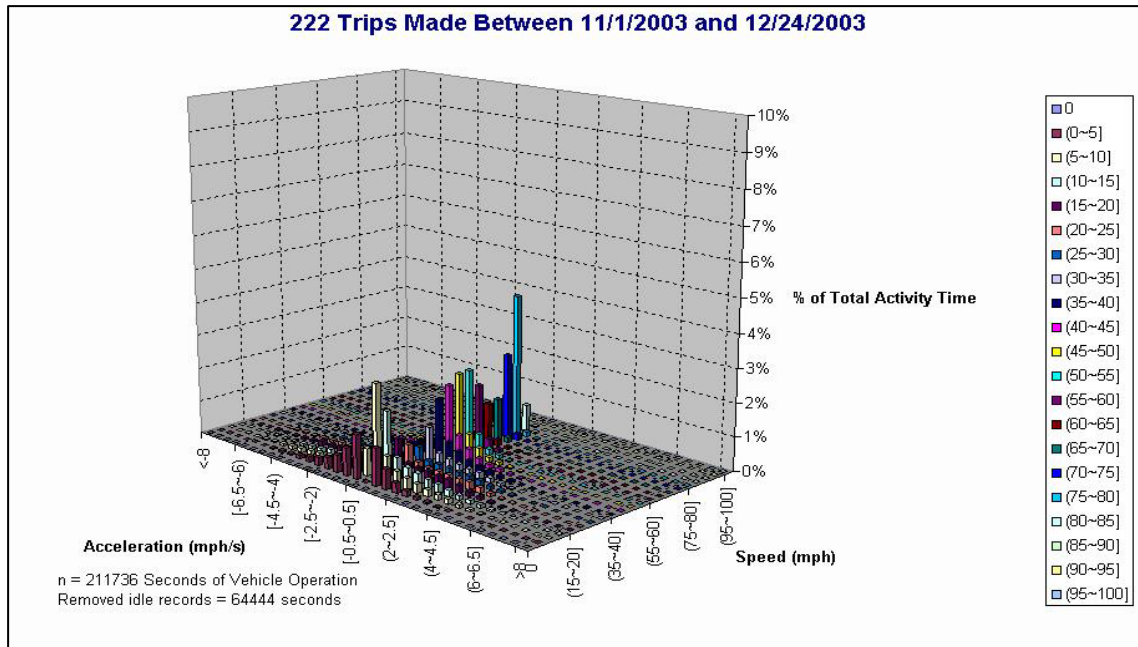


Figure 36 Watson Plot Example

Summarize acceleration data

As with the GPS matched trip files, the Watson plot files are numerous, even when summarized at the posted speed limit for each driver. Therefore, this information is further summarized by driver. Because most of the speeding data are summarized in the trip tables, the focus of the Watson summary is on acceleration data, specifically grouped by speeding behavior as well as by acceleration range. Given that the acceleration data is calculated from the GPS speed data, its accuracy is only within 1 mph/s. Therefore, groups of acceleration and deceleration data are formed for each 2 mph/s range (0-2, 2-4, 4-6, and 6-8 mph/s), with the 6-8 mph/s group regarded as the most extreme acceleration. Higher values are included in this bin, therefore this bin is actually > 6 mph/s.

Merge trip and Watson summaries with driver socio-demographic data

Merging the trip and acceleration summaries with the socio-demographic data into one analysis file is the last of 11 processing steps. This step includes an iterative merge process to incorporate data from multiple files and multiple data sources. Previously provided in Chapter 4, Figure 7 provides a summary of the data sources, some data elements of interest, and the development of the final file for speeding profile development. Not only can this table be used for analysis at the individual level, but also serves as a source for categorical data analysis techniques as well as model development.

Chapter Six

SAMPLE SELECTION

The selection of the sample for this research was based on an iterative process of data processing and verification. The size of the sample was ultimately chosen based on the amount of time required for data processing. Additionally, the study of individual driver speeding behavior requires specific criteria for sample selection:

- Positive driver identification (or single driver vehicle 95% or more of the time)
- Valid speed measurements from in-vehicle equipment
- Correctly matched measured speed with posted speed limits or other criteria
- Sufficient data available for statistical analysis

These criteria actually drove the development of the filters during the processing steps. The application of the process filters significantly reduced the size of the valid sample from 477 vehicles to 230 vehicles as shown in Table 15.

Recall that age is one of the primary factors of significance found in the previous research. Categorical analysis based on age will be one of the primary analytical measures for this study. Table 15 shows the effects of the filters on potential participants grouped by age. Both ends of the age spectrum, young and older, have limited initial sample. It would be of interest to study differences between drivers age 15-19 and 20-24 as well as drivers age 75+, however, to provide adequate sample size for statistical analysis, researchers merged these groups. The age categories include drivers age 15-24, 25-34, 35-44, 45-54, 55-64, and 65+.

Table 15 Filter Effects on Commute Atlanta Sample

Filter	Age Categories							Total
	15-24	25-34	35-44	45-54	55-64	65+	Ukn	
Total Available Sample	31	57	109	112	100	60	8	477
Sample Removed By Filters								
1. Shared vehicle	3	9	32	20	19	13	2	98
2. Large percent of out of area travel	(4)	10	13	19	19	10	2	77
3. No valid GPS records	5	3	3	12	9	4	3	39
4. Large percent of invalid GPS records		1	4		1	1		7
5. Minimal time spent driving (<30 minutes)			1	2				3
6. Low percent match of speed and speed limit		4	4	7	6	1		22
7. No Age							1	1
Remaining Sample	19+(4)	30	52	52	46	31		234

The age categories in Table 15 are used for most of the descriptive statistics and categorical analysis. However, based on initial regression tree analysis (age division at 39 years) and the groupings used by the National Highway Traffic Safety Administration for young drivers, the age groups are sometimes used in 5-year increments (15-19, 20-24, 25-29, etc.) in the analysis.

To devise a sampling scheme, researchers retrieved information from the GA DMVS regarding the number of licensed drivers by county, age, and gender. Table 16 provides a breakdown of the comparison between the potential Commute Atlanta driver sample, and the general 13-county licensed driver population. The Commute Atlanta driver sample is significantly low in the 25-35 age category, and high in 54-64 age category (note that the Commute Atlanta sample was not designed for use in a safety study, but

rather for a road pricing experiment). Initially, researchers envisioned matching the sample selection with the distribution of licensed drivers by age group. However, the younger driver sample (ages 15-34) is insufficient. A secondary approach is to select a significant and equal sample from each age category. Returning to Table 15, the maximum sample size for age category 65+ is 31, 30 for age category 25-34, and 19 for age category 15-24.

The young driver group is unfortunately the least populated portion of the sample, yet they are one of the most interesting in terms of previous research and fatal crash involvement. Many of the potential Commute Atlanta young drivers do not have a primary vehicle assignment, nor drivers' license, and therefore were not included in the valid sample. Positive driver identification systems may have improved this, but also might have influenced driver behavior. Further, a substantial portion of young male drivers assigned as primary driver (5 of 12, or 42%) were driving vehicles that were not reporting valid trip data. In comparison, none of the vehicles driven by young females were malfunctioning. One of the male vehicles was reporting trip files, but without GPS data. Disconnecting the GPS antenna would be sufficient cause for this error. This raises suspicions that young males may be tampering with the monitoring devices. There is one known occurrence of intentional tampering by a 17-year-old driver reported by the installer. These boxes have been scheduled for recall, and a determination of tampering will be made at the time of removal.

Table 16 Comparison of Age/Gender using DMVS Licensed Driver Data

Georgia Licensed Drivers in 13-county Area during 2003 by Age and Gender

	Age Category						
Gender	15-24	25-34	35-44	45-54	55-64	65+	Total
Male	236583	385529	400928	300235	181720	121947	1626942
Female	237191	396646	399106	312777	184709	136325	1666754
							3293696

Percentage of 13-county Licensed Drivers by Age and Gender

Male	0.499358	0.492894	0.501139	0.48977	0.495921	0.472165	0.493956
Female	0.500642	0.507106	0.498861	0.51023	0.504079	0.527835	0.506044

Percentage of 13-county Licensed Drivers by age category

% of Total	14.38	23.75	24.29	18.61	11.13	7.84	100.00
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Compared to Commute Atlanta Potential Driver Population (All Members Age >=15)

Age	15-24	25-34	35-44	45-54	55-64	65+	Total
Male	72	44	85	82	69	55	407
Female	74	51	122	105	95	54	501
Total	146	95	207	187	164	109	908
% of Total	16.08	10.46	22.80	20.59	18.06	12.00	100.00

Difference between Commute Atlanta and 13-county							
	1.70	-13.29	-1.49	1.98	6.94	4.16	0.00
High or Low	HIGH	LOW	LOW	HIGH	HIGH	HIGH	HIGH

Researchers continued with the sample selection of equal size groups in each category with a 50/50 split between male and female to represent the population statistics. Using the 24-35 and 65+ age categories as the basis, the cell size for each age category was set to 30, with 15 males and 15 females selected for each group. The final distribution of the sample is shown in Figure 37.

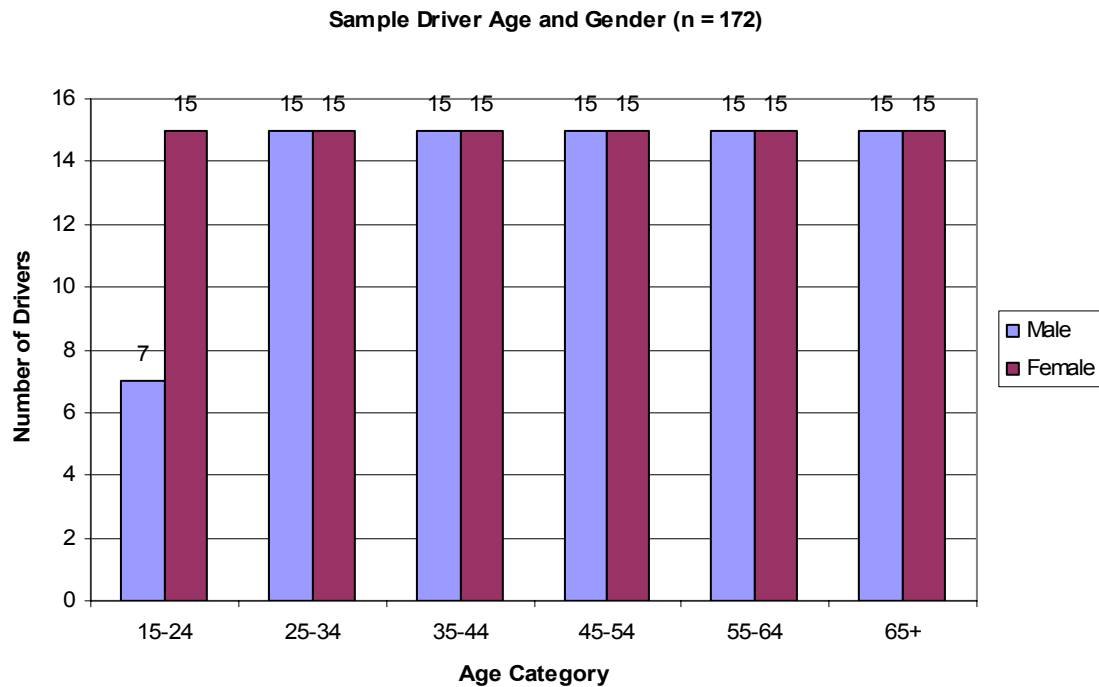


Figure 37 Speed Study Sample Distribution by Age and Gender

The 15-24 age group indicates 22 participants. As discussed earlier, by reducing the restrictions imposed by the out of area filter for this group, the female sample was met, and the male sample in this age group was increased by two meeting nearly half of the targeted cell size. The final sample includes 172 individual drivers.

For some categories, 15-24, 24-35 and 65+, researchers retained nearly the entire valid sample; however, for the middle categories, sample selection used a random selection process. Groups were formed for each age group and gender, and a range of random numbers (1-n, where n equals group size) was assigned to each valid driver. A second draw of 15 random numbers from this range produced the sample selection.

Sample Statistics

It is important to understand how the selected sample compares with the sample from which it was drawn, as well as to the general population. Of the 172 individual drivers, there are 142 households represented. These 142 households are not significantly different from the 268 households participating in the Commute Atlanta program based on the results of a chi-square test with significance level of 0.92. Table 17 gives the samples for each group along with the representative percentages.

Table 17 Comparison of Commute Atlanta and Speed Study Households

Annual Income	HH Size	# Vehicles	Population %	Target	Commute Atlanta Sample	Commute Atlanta %	Speed Study Sample	Speed Study %
Any	Any	0	7.4	0	0	0.0	0	0.0
<30k	Any	1+	18.4	40	20	7.5	10	7.0
30-75k	1	1+	11.3	40	34	12.7	16	11.3
30-75k	2+	1	6.8	40	18	6.7	7	4.9
30-75k	2	2+	10.6	40	38	14.2	21	14.8
30-75k	3+	2+	13.9	40	34	12.7	16	11.3
75+	1	1+	2.8	0	5	1.9	2	1.4
75-100k	2+	1+	12.1	40	41	15.3	22	15.5
>100k	2+	1+	16.8	40	73	27.2	48	33.8
Unknown	Any	Any	n/a	0	5	1.9	0	0.0
			100	280	268	100.0	142	100.0

Household Location

The following graphics provide visual representations of the sample by household location. Figure 38 provides the location of the 142 sample households in relation to the 13-county area. The sample skews somewhat to the northern metro area. Given the income level of the households, this is not surprising. Figure 39 shows the same household locations coded by income level.

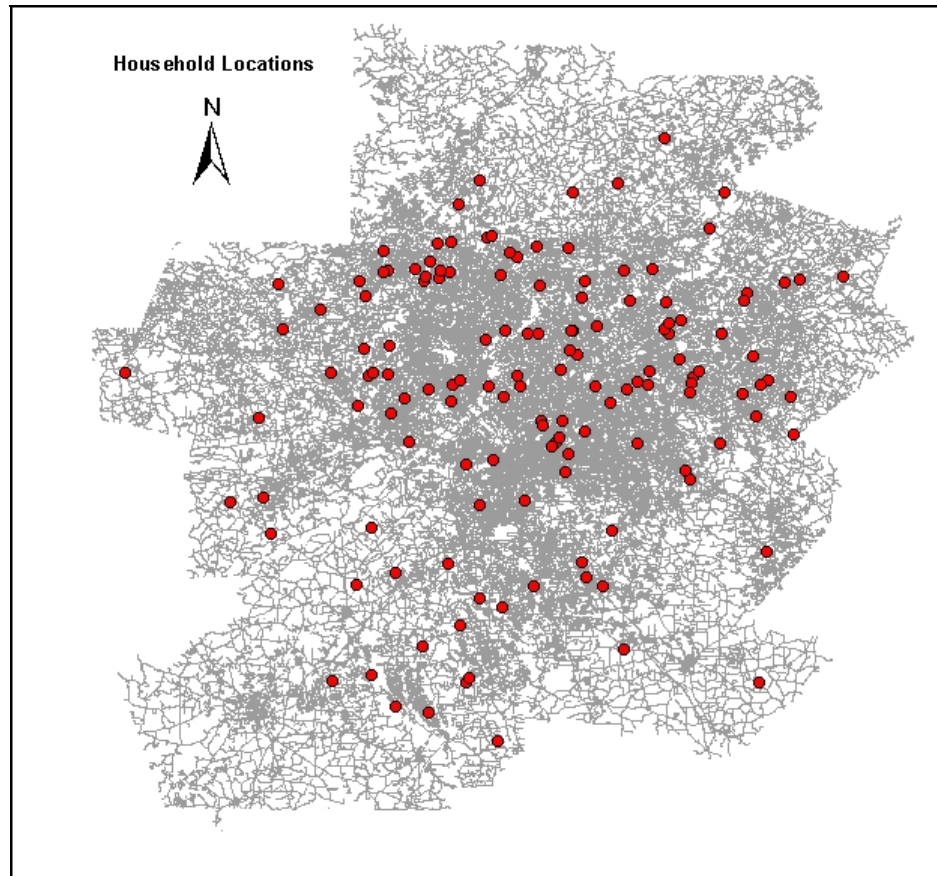


Figure 38 Driver Speed Study Household Locations

Figure 40 provides household locations coded by ethnicity, and Figure 41 shows locations coded by driver age. There are clear differences in the locations of ethnic populations across the area. These differences in geographic location may influence driver behavior and therefore, this variable will not be used to model speeding behavior. The young driver population has a slight skew to the northern suburbs, however, age has continuously been shown to be a major factor in driver speeding behavior. This variable is expected to have a significant effect on speeding.

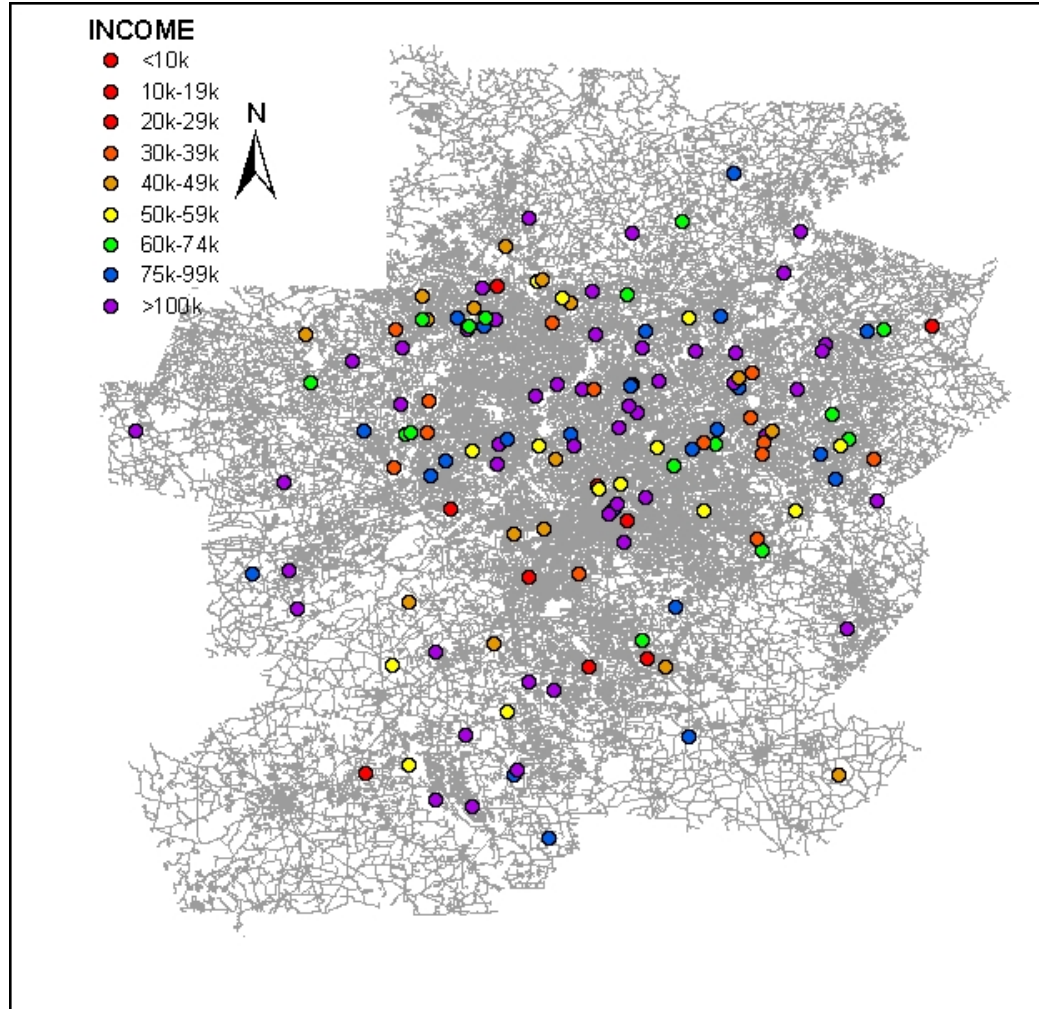


Figure 39 Sample Household Locations by Income

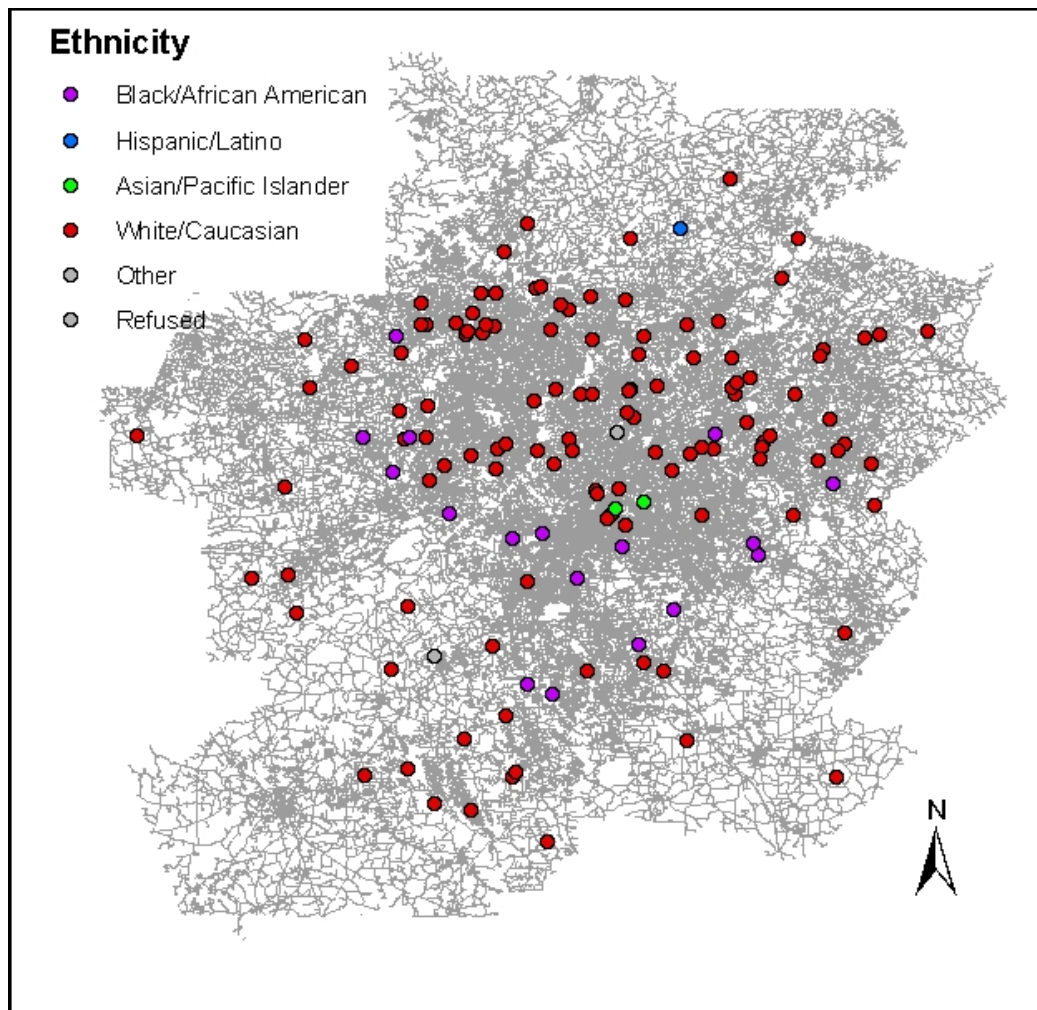


Figure 40 Sample Household Location by Ethnicity

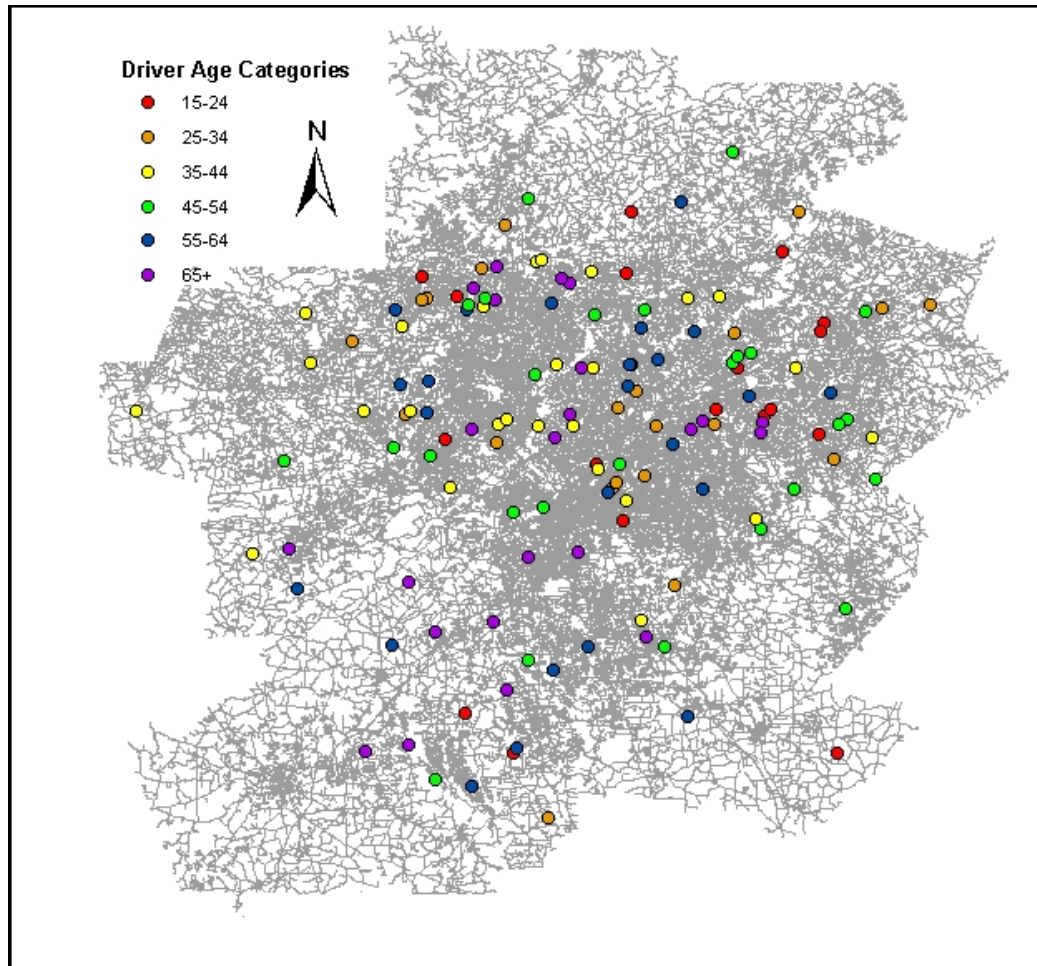


Figure 41 Sample Household Location by Age

Vehicle Year, Make, Model and Type

The majority of the vehicles driven in the sample are less than 10 years old (see Figure 42). Approximately one-third of the vehicles are less than four years old, and only 10% are more than 10 years old. Figure 43 shows that 41% of younger drivers and 43% of older drivers drive cars 10 or more years old, compared to approximately 20% of all drivers age 25-64. This could attribute to increased injuries during crashes due to limited safety features available on these models.

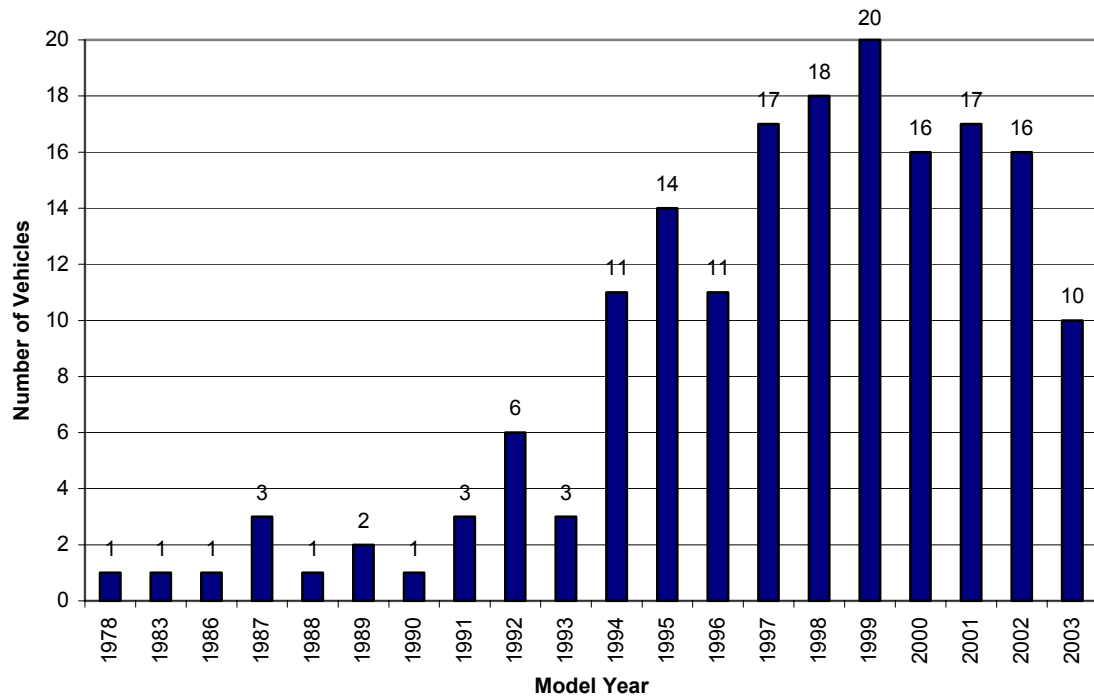


Figure 42 Vehicle Year Distribution

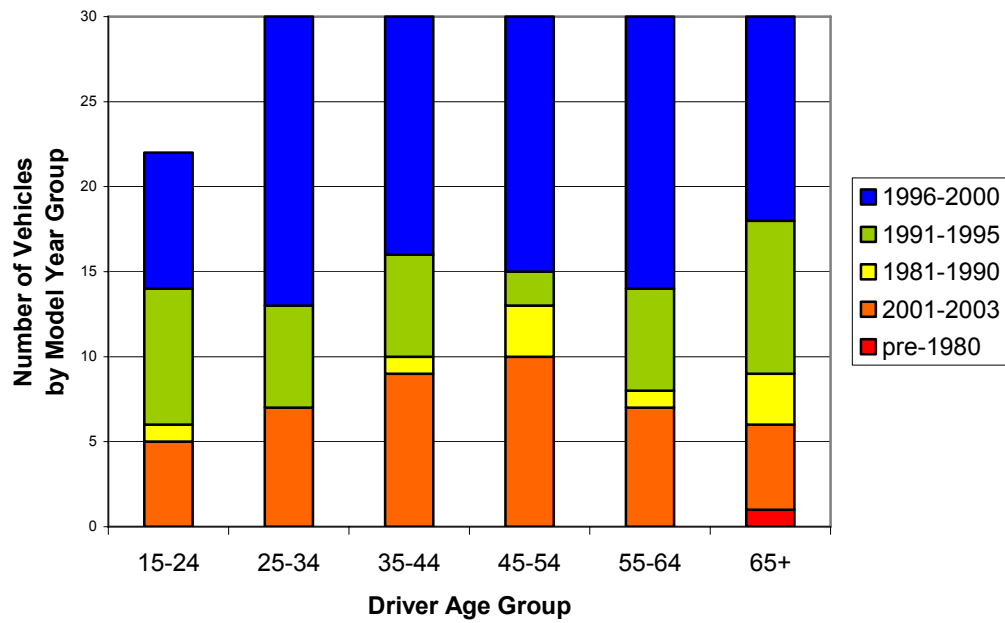


Figure 43 Vehicle Model Year Distribution by Driver Age Group

By gender, there are significant differences in the type of vehicle driven. Males tend to drive pick-up trucks, SUV's, and vans in similar proportions to autos. Females rarely drive pickups, and the primary vehicle is the auto followed by SUVs and vans. Figure 44 provides the actual distribution of vehicle body type by gender.

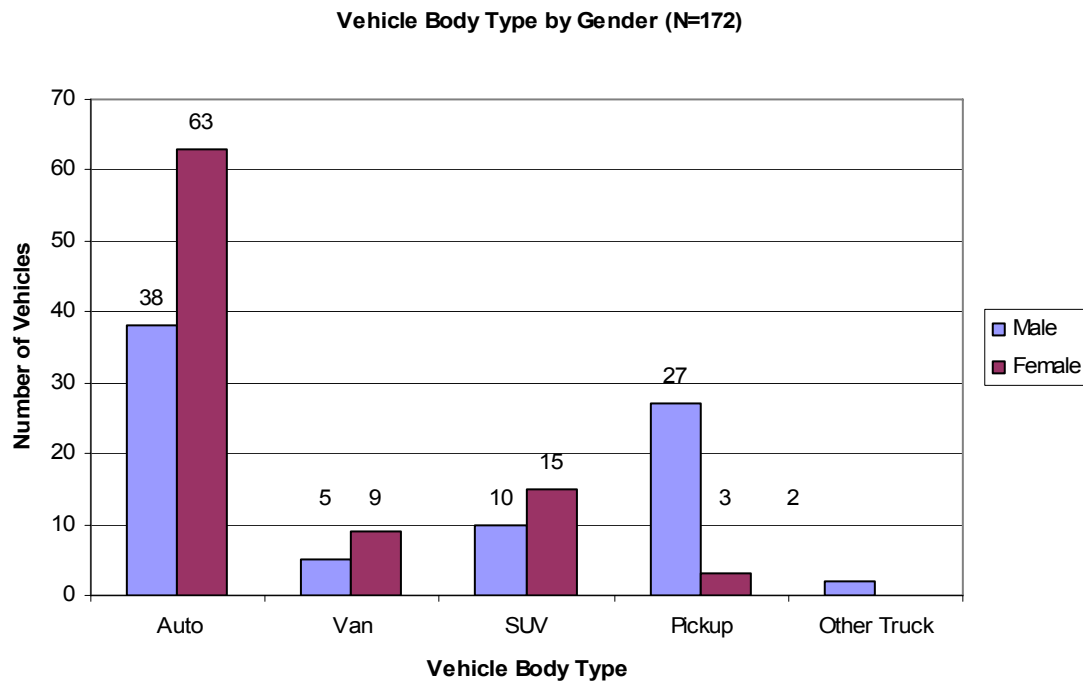


Figure 44 Vehicle Body Type by Driver Gender

Figure 45 provides the distribution of vehicle type by driver age. The younger driver sample (ages 15-34) primarily drive autos with a small percentage of pickups and SUVs. Vans are driven only by the 35 and older age groups, with a higher percentage in the 35-55 segments. Pickup trucks are driven almost equally among the 35 and older age groups.

The distributions of vehicle type are further broken down to represent age and gender in Figure 46 and Figure 47. In the male portion of the sample, pickup trucks and SUV's are the primary vehicle type for the 35-44 age group. As age increases, pickup trucks and SUV's diminish in proportion to autos. In the female sample group, there is a clear tendency toward vans in the 35-55 age groups. In the 35-44 age group, vans and SUVs are driven in equal proportion to autos, signaling the presence of children in the household.

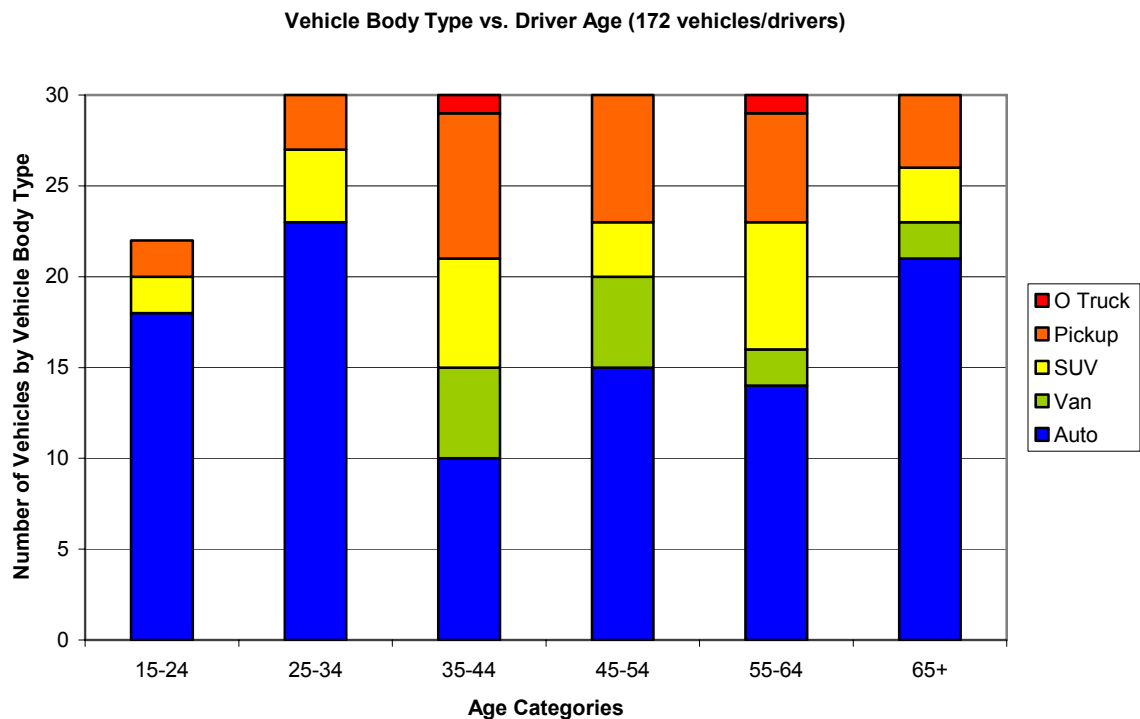


Figure 45 Vehicle Body Type by Driver Age

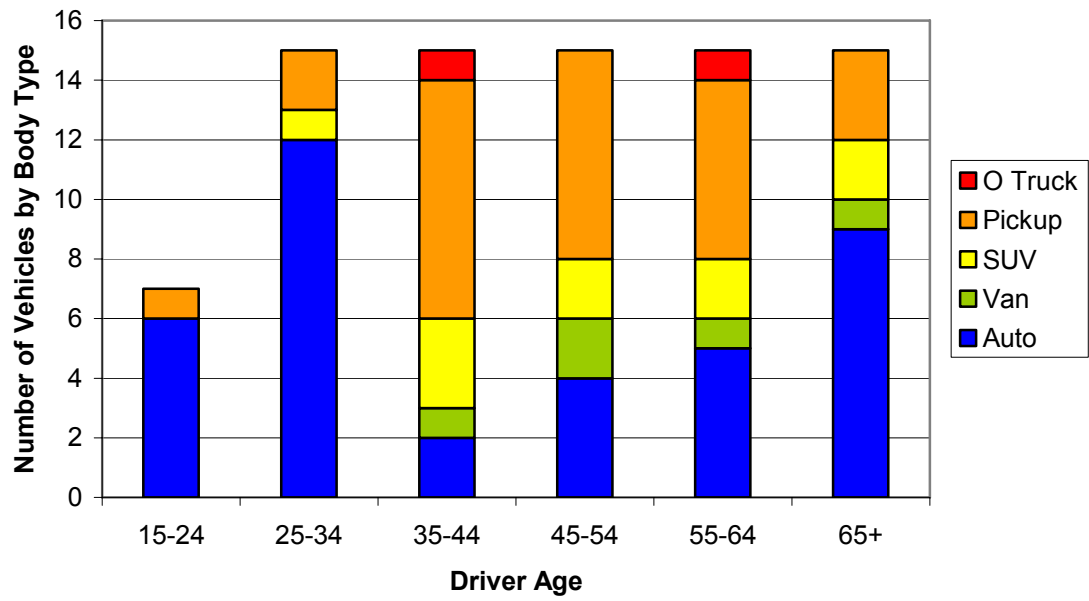


Figure 46 Vehicle Body Type by Driver Age (Males Only)

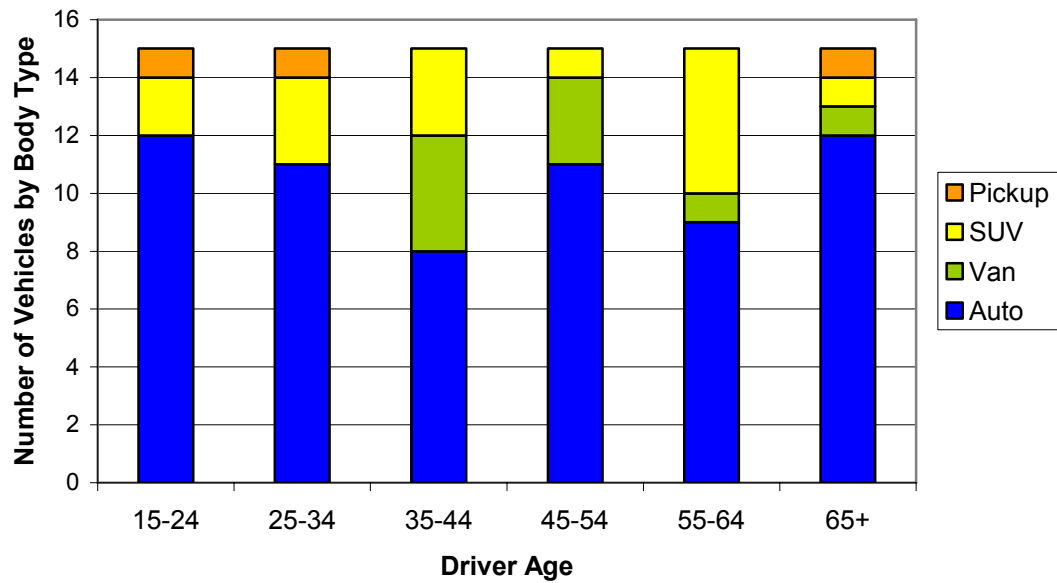


Figure 47 Vehicle Body Type by Driver Age (Females Only)

Driver Work Status

Figure 48 provides the proportion of drivers by work status, and the type of vehicles driven. The majority of the sample works full-time. A handful are homemakers, as expected, vans are popular with this group. Figure 49 provides work status by age. Drivers in the 15-24 age group are primarily unemployed or part-time workers, whereas drivers in the 65+ age group are nearly all retired. The 55-64 age group also has a significant proportion of retired drivers.

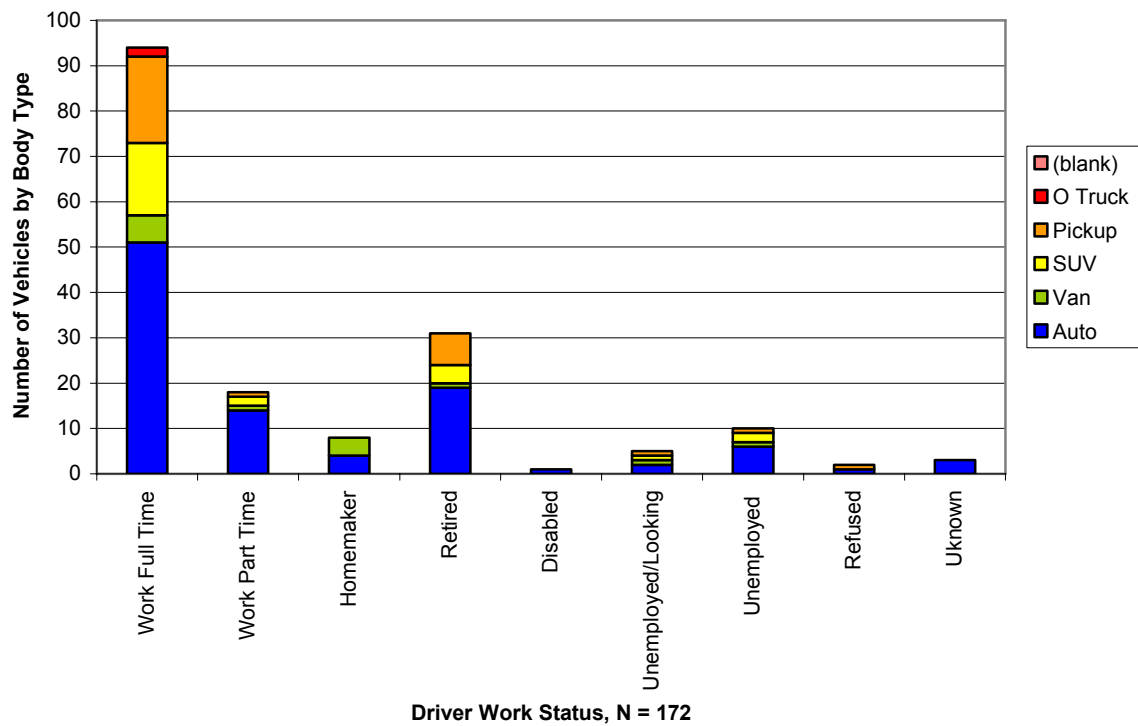


Figure 48 Vehicle Body Type by Driver Work Status

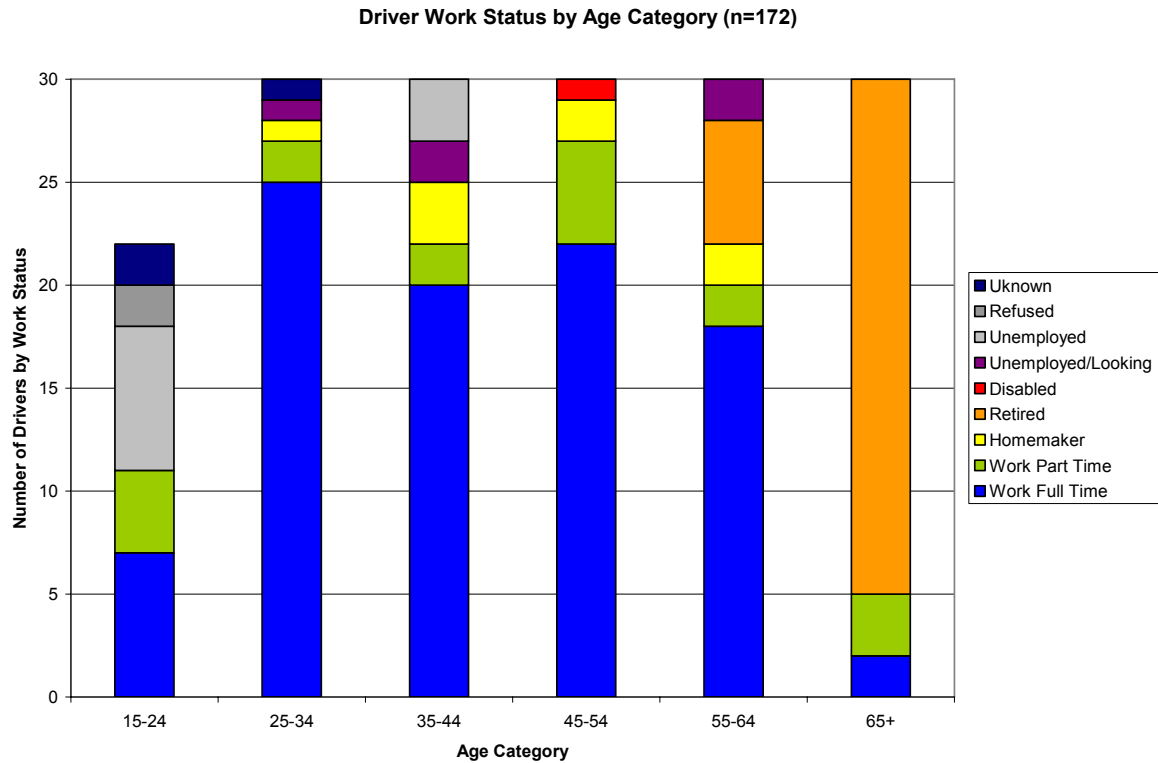


Figure 49 Driver Work Status by Age

Driver Education Attainment

From Figure 50, the educational level of the sample is clearly skewed toward the highly educated. 137 drivers out of 172 (79%) have had at least some college. Using the 2000 Census data as a reference, the percentage of the driving age population in the 13-county area with at least some college education is 62%. Of the seven individuals with education level less than high school, five are still attending high school.

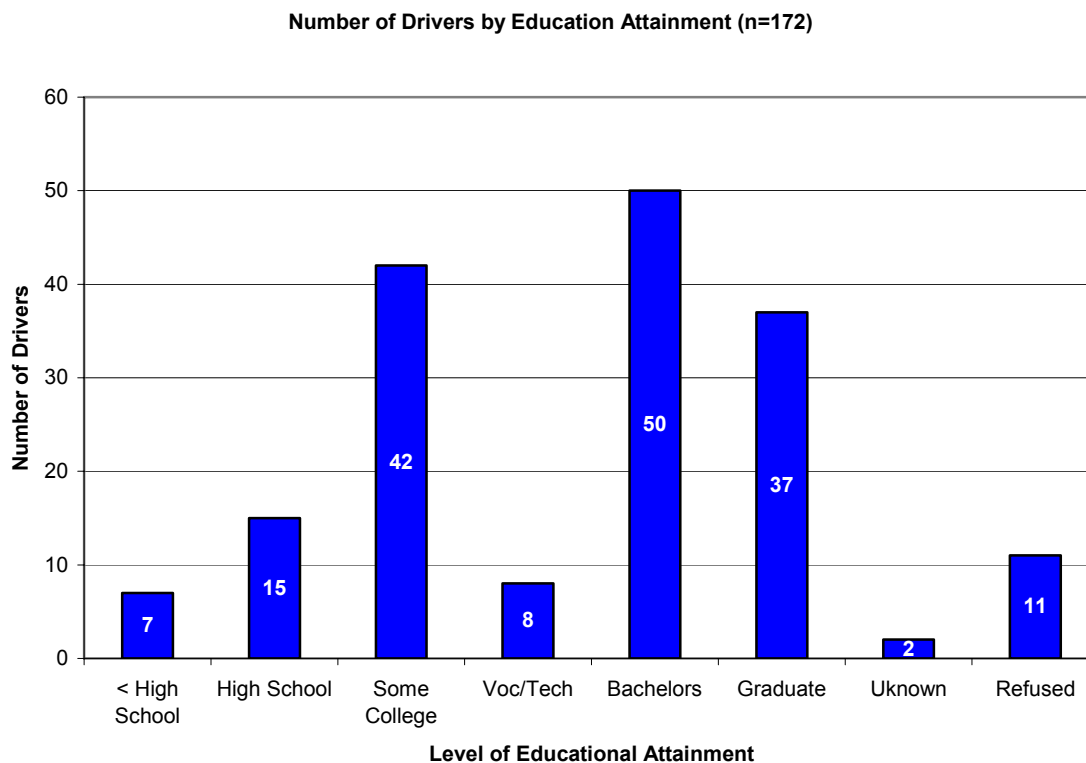


Figure 50 Distribution of Education Attainment

Household Income

The household income levels of the Commute Atlanta Sample are somewhat skewed to the high side as mentioned earlier in the chapter on Data Collection. The same is evident in the chose speed study. The total sample in the range less than \$30,000 annual household income is 20 households, of which 12 vehicles are represented in this study. Another item worth mentioning is that we do not have individual income in the dataset – only total household income. Therefore, minors in the study still living with their parents are reported as having the household income. Many of these are situated in the top five income ranges.

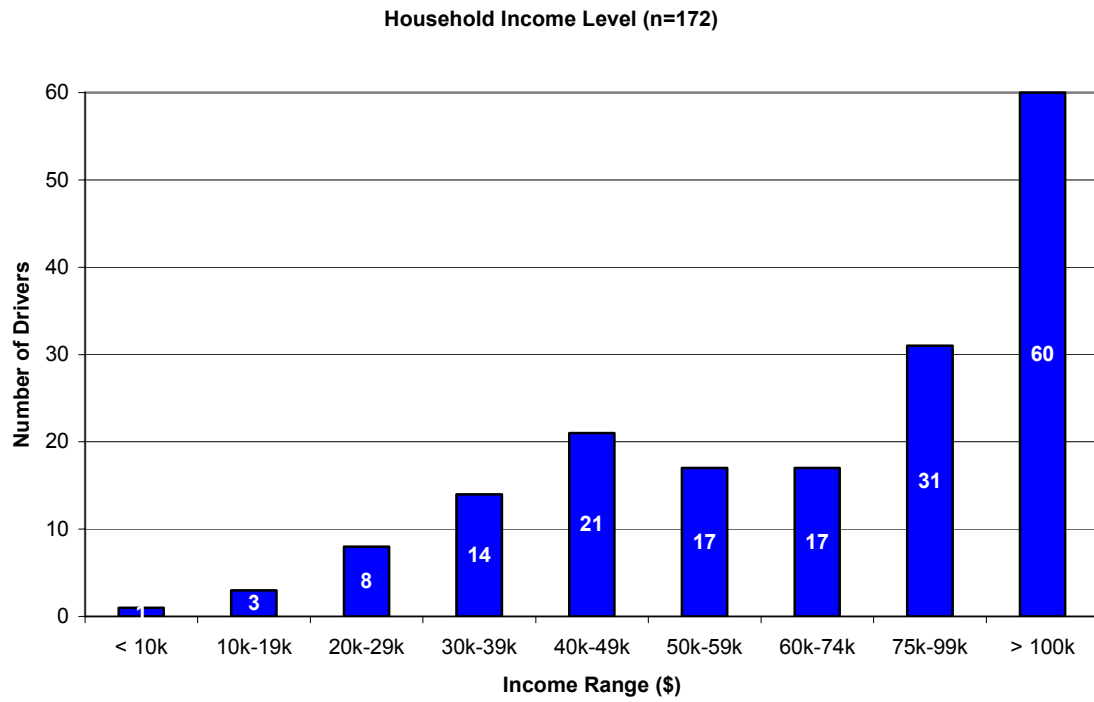


Figure 51 Distribution of Household Income

DATA ANALYSIS AND OBSERVATIONAL CODES

The goal of this research is to develop a framework and methods for quantifying and analyzing individual driver behavior; thus, allowing the identification of speeding behavior either for post-crash analysis or pre-crash behavioral intervention. Previous research regarding speeding behavior has been constrained by the lack of a common definition for speeding and the difficulty of obtaining precise scientific measurements of actual vehicle speeds over an array of exposure scenarios. Research on the outcome of speeding is further complicated by the very nature of motor vehicle crashes. Motor vehicle crashes involve a complex series of events and behaviors, the study of which spans an array of areas including environmental, sociological, psychological, and engineering. Strict linear association with any single contributing factor is confounded by numerous other contributing factors, which add to or take away from the risk. Some researchers may be trained in engineering but have little familiarity with sociology or psychology. The explicit incorporation of the interdisciplinary nature of motor vehicle crashes is a necessary component in this type of research.

It is still unknown whether participating in speeding behavior actually increases the risk of involvement in a crash. However, it is well known that speeding does increase the severity of crashes when they occur. Kloeden et al. (2002) found that the relative risk of being involved in a casualty crash approximately doubles for each 3.1 mph increase in free traveling speed. Their research suggests that reductions in driver speeding behavior could

provide substantial reductions in casualty crashes as well as reductions in injury and property damage only crashes.

The basic theoretical model (see Figure 52) used in the development of this research includes speeding as a contributing factor to crash involvement as described in the following sequence:

1. Driver speeding behavior is attributable to certain socio-demographic and exposure characteristics (aggregate)
2. Driver speeding behavior can be associated with certain trip level attributes such as trip length, area of travel, and trip time (disaggregate)
3. Driver speeding behavior is a precursor to crash involvement and crash severity
4. Crash severity is a function of local conditions, vehicle type, crash conditions, etc.

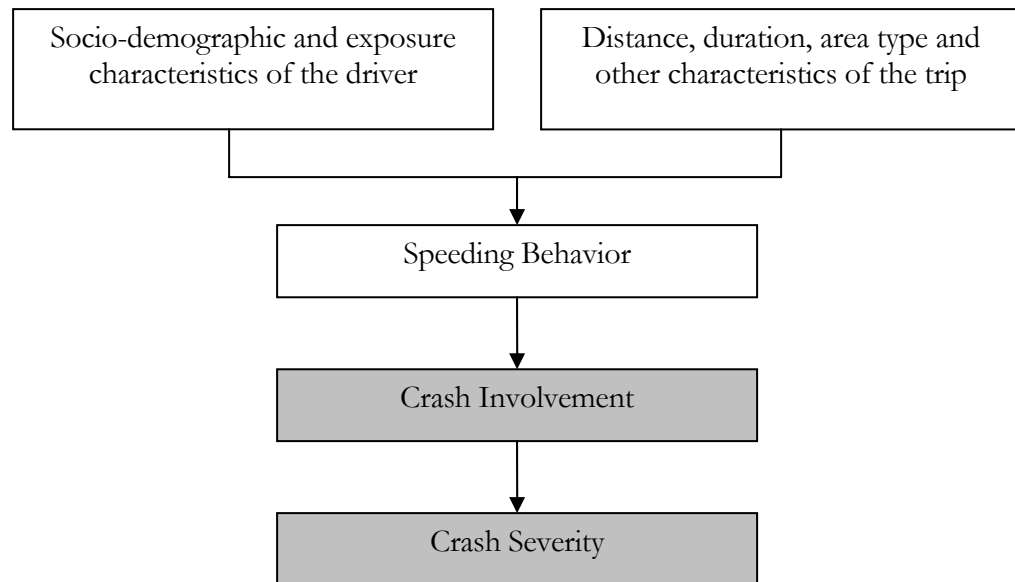


Figure 52 Speeding Behavior Leads to Crashes

This model can support the study of other behaviors that may contribute to crashes. Instead of speeding, researchers might study aggressive driving as defined by hard accelerations and decelerations, or rapid lane changes (weaving). Additionally, combinations of behaviors may be included with safety belt use and turn signal use. As expected, limited numbers of crashes occurred during the baseline data collection phase limiting the ability to study the relationship between speeding and crash involvement. The random and rare nature of crashes would require many studies, such as this, to absolutely resolve this dilemma.

Analysis Methodology

The effects of driver's socio-demographics, operating environment, vehicle miles of travel, facility-specific exposure, physical ability, and attitudes on speeding behavior are complex. Much can be learned from previous research and knowledge; however, many new insights are afforded through this research due to the novelty and advances in technology. The analysis followed a three-pronged approach:

1. Describe the univariate and bivariate trends in the data through examination and description using statistics, graphs, and plots.
2. Define case study samples that are representative of various groups, exposure, and speeding behavior. Develop metrics to present the data with regard to speed.
3. Develop multivariable modeling frameworks to study speeding behavior in relation to driver and environmental characteristics.

Detailed descriptions of each of these methods follows.

Descriptive Statistics

The initial step of the analysis included the detailed description of the data using a number of techniques. It should be noted that these techniques were most useful for assessing univariate and bivariate aspects of the data, while multivariate relationships were examined using more sophisticated methods. A thorough description of the driver exposure, socio-demographics, etc., allowed examination of the trends in the data. Examples of tools used to describe the data include simple summary statistics such as means, modes, medians, and ranges. Plots and graphs including error bars, frequency and relative frequency histograms, scatter plots, and bar charts were used extensively. Attempts were made to test previously held assumptions concerning speeding such as overrepresentation by males, young drivers, and participants with high incomes, as well as overrepresentation during the late evening/early morning hours.

Case Studies

The use of case studies is important in acquiring an understanding of the data format and the outcome of using aggregate functions to summarize the data. For this research, it is important to examine an array of drivers of different age and gender with observable differences in speed and exposure. Six drivers were chosen for this component with ages ranging from 16 to 77. For each driver, a detailed individual assessment of speeding was completed. The assessments were compared to average measures obtained for the whole sample and sample groups during the development of descriptive statistics. This component allows researchers to observe potential variability between drivers and within drivers, which can be important in later model development.

Additionally, this step is important in the development of metrics for speeding behavior. During this task, several metrics were found to be helpful in portraying the information contained in the thousands of records recorded for each trip. One metric describes the amount and level of speeding through a histogram of activity occurring in speed bins below and above the posted speed limit. The histograms can be developed for each posted speed limit, each functional class, as well as combinations of either of these variables. Figure 53 provides an example of a histogram for Driver 6279 for functional class of urban interstate principal arterial (posted speed limits between 55 and 65 mph). This histogram shows the amount of activity⁶ less than 10 mph below the posted speed limit in the first bin. The second bin indicates the amount of activity occurring between 10 mph below the posted speed limit and the posted speed limit. Subsequent bins indicate speeding in 5 mph increments, 0 to 5 mph over, 5 to 10 mph over, etc. Note that this histogram indicates large amounts of speeding in high-speed ranges. At 55 mph, the activity in the bin of 35 to 40 mph over the posted speed limit indicates speeds of 90 to 95 mph. The amount activity in each of these bins can be combined to provide a measure of percent of observations above the posted speed limit or percent of observations above the posted speed limit plus xx mph. A similar charting method, the Watson plot (shown earlier in Figure 36), combines the speed distribution from 0 to 100 mph with acceleration information.

⁶ Note that activity refers to vehicle operation when speeds are greater than 5 mph.

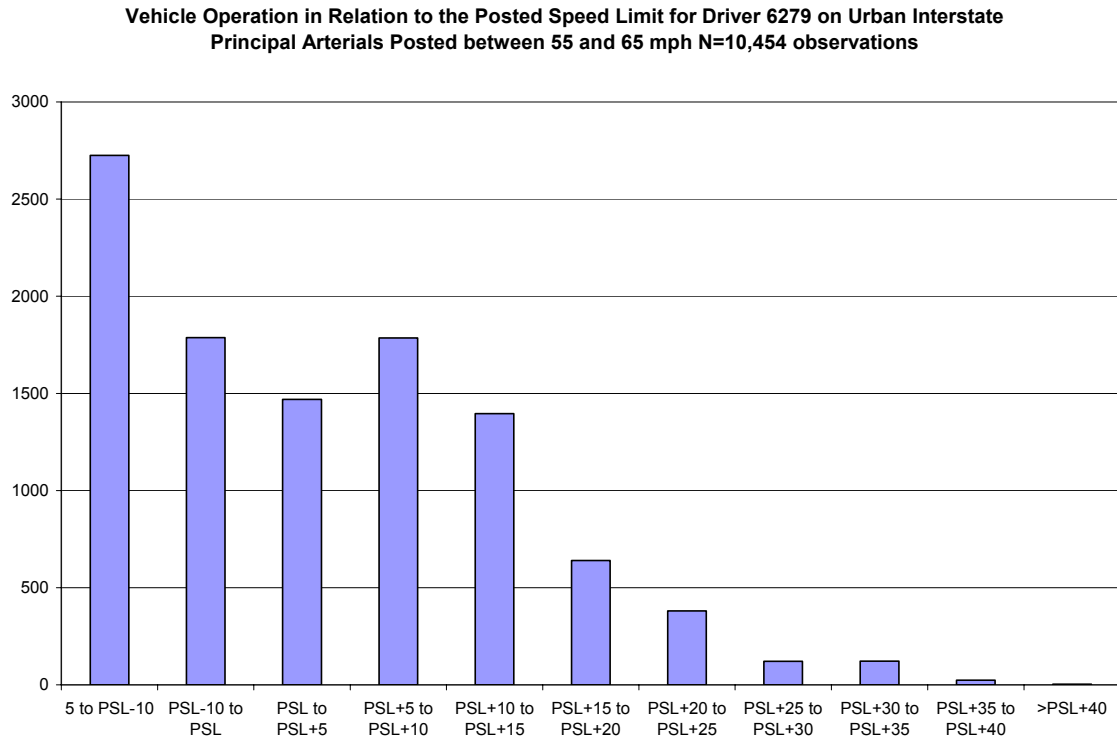


Figure 53 Speeding on Urban Interstates by Driver 6279

Another metric for combining the amount of speeding over the limit with the extent of speeding over the limit is the mean positive deviation from the posted speed limit. This is calculated by summing the positive differences between the posted speed and the actual speed for each trip record and dividing by the number of records where the driver was speeding. Unfortunately, this metric has the tendency to underestimate extreme speeds. The effect of this tendency is even worse when the shape of the speeding distribution is skewed heavily to one side or the other, which is common in analyzing the speeding tail of a speed distribution.

Analytical Modeling Framework

Finally, a relationship was sought between speeding behavior and driving conditions and/or driver characteristics. The basic theoretical model described earlier in this chapter was used as the foundation for the statistical model development. Two hypotheses regarding speeding behavior and the corresponding model formulations are listed below.

1. Driver speeding behavior is attributable to certain socio-demographic and exposure attributes
 - Speeding Behavior Model 1 (aggregate logistic regression)
2. Driver speeding behavior can be associated with certain trip level attributes
 - Speeding Behavior Model 2 (disaggregate logistic regression)

The logistic regression model is a flexible tool for studying the relationship between a set of variables and a categorical outcome. This model is appropriate for determining driver and trip related characteristics that are important for the identification of speeders. In this research, there is interest in the definition of groups with the propensity to speed more and at higher extremes than others. Using logistic regression, either a binary category of speeder/non-speeder, or various levels of speeders can be predicted using the independent variables.

Logistic regression allows the direct estimation of the probability of an event occurring given values of the independent variables. For multiple independent variables, the logistic regression model is

$$\text{Prob (event)} = \frac{1}{1 + e^{-Z}}$$

where,

Z is the linear combination $Z = B_0 + B_1X_1 + B_2X_2 + \dots + B_pX_p$, and

p is the number of independent variables.

The independent variables are a mixture of categorical data (driver gender, roadway functional class, etc.) and continuous (driver age, total exposure, etc.).

Speeding Behavior Model 1

This model supports Hypothesis 1 - Driver speeding behavior is attributable to certain socio-demographic and exposure attributes. The general model form for the aggregate speeding behavior models is:

$$\text{Speeding behavior} = f(\beta_1X_1 + \beta_2X_2 + \beta_3X_3)$$

where,

Speeding behavior = speed as percentile speed or mph over speed limit

X_1 = socio-demographic variables

X_2 = driver performance variables

X_3 = vehicle variables

Appendix G provides a listing of available variables explored for incorporation in aggregate speeding models. These models will be useful for explaining chronic patterns of speeding among the population, because all trips and driving is aggregated in this model.

Speeding Behavior Model 2

This model supports Hypothesis 2 - Driver speeding behavior can be associated with certain trip level attributes. This model of speeding behavior will focus on trip-level

speed. This disaggregate speed driving model will be more adept at capturing factors of individual trips that might lead to a driver speeding.

$$\text{Speeding behavior} = f(\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4)$$

where,

Speeding behavior = speed as percentile speed or mph over speed limit

X_1 = socio-demographic variables

X_2 = driver performance variables

X_3 = vehicle variables

X_4 = trip variables

Appendix G provides a listing of available variables explored for incorporation into disaggregate speeding models. These models will be useful for explaining specific factors for individual drivers on specific trips.

Observational Coding

The underlying objective of developing driver profiles is to define, in some manner, the amount of time (or distance) during which a particular driver/vehicle is participating in speeding behavior. In defining these driver profiles, it is important to factor in each driver's speeding behavior with respect to roadway functional class and posted speed limit. However, it is imperative to define speeding in a consistent manner such that it is not confused during the analysis. For this reason, the following observational terminology is provided.

- Trip – engine-on to engine-off
- Observations – individual seconds of driving activity

- Driver Speed – recorded GPS speed
- Posted Speed Limit - PSL indicated in GDOT RC file
- Functional Class – roadway type indicated in RC file
- Constrained Speed – driving activity below the PSL
- Speeding Opportunity or Unconstrained Speed – driving activity at or above PSL
- Limit-based Speeding – speed exceeding PSL
- Legislated Enforcement Limit – Georgia Code requires a driver to exceed the posted speed limit by 10 or more mph to be cited by local police officers
- Compliant speed – speeds not exceeding a threshold set a PSL + 10 mph
- Non-compliant speed – speed exceeding PSL+10mph, speeding behavior sufficient for receipt of citation
- Idle Activity – GPS speed < 5 mph (removed before analysis)
- Activity – vehicle operation where GPS speed \Rightarrow 5 mph

Chapter Eight

RESULTS

The results of this research are presented in five sections. The first section includes general statistics regarding the processed trip data. The second section provides descriptions of a few metrics used to portray speeding behavior. Section three compares speeding behavior across driver and trip characteristics using descriptive statistics. In the fourth section, case studies of individual driver speeding behaviors are presented to showcase some of the general differences between drivers. Finally, the results of the exploratory model development activities are presented along with recommendations for future models.

Trip Statistics

The data processing steps described in chapter six were conducted on data collected over a 16-day observation period from March 8-23, 2004 from the sample of 172 drivers. In total, researchers processed 12,424 trips. Of these 12,424 trips, only 10,627 valid⁷ trips remained after the filter process. The breakdown of filtered trips is as follows:

- 292 trips were removed because they did not contain any valid data points;
- 179 trips were removed because all valid data were out of the study area;
- 150 trips were removed because they were only partially in the study area; and
- 1,176 trips were removed due to minimal number of valid records (< 20 observations).

⁷ Valid GPS points are those based on signals from 4 or more satellites, and with a positional dilution of precision (PDOP) between 1 and 8.

The 10,627 valid trips represent 3,332 hours of vehicle operation, and 84,365 miles of travel over the 16-day period. After removing records related to interstate entrance/exit ramp activity⁸, there were a total of 8,362,582 seconds of valid GPS data in the dataset with the following breakout:

- 1,880,195 valid observations (speed < 5 mph);
- 6,482,387 valid observations with associated road characteristics (speed > 5 mph);
- 2,874,907 valid observations with associated road characteristics (speed > PSL);
- 398,771 valid observations with associated road characteristics (speed > 15 mph above the posted speed limit).

The distribution of trips by trip duration is shown in Figure 54. The bins for trip duration start with 0-5 minutes and range to over 40 minutes. 11% of the trip durations are less than 5 minutes, 27% are 5-10 minutes, and 17% are 10-15 minutes. The majority (55%) of trips are less than 15 minutes in duration. A similar distribution of trips by trip distance is shown in Figure 55. The bins for trip distance start with 0-5 miles and range to over 60 miles. The majority (53%) of trips are less than 5 miles in length.

Figures 60 and 61 show the distribution of trips by trip start hour starting at midnight and ending at 11 PM. Figure 61 also shows the percentage of trips made during weekday versus weekend by each trip start hour. As expected a small portion of trips are made between midnight and 5 AM, and the majority of the trips are made during the daytime hours.

⁸ Initial analysis of these 10,627 trips showed extreme deviations between the driver speed and posted speed at interstate ramp locations. These differences were associated with very low posted speeds on ramps and rather high exiting speeds.

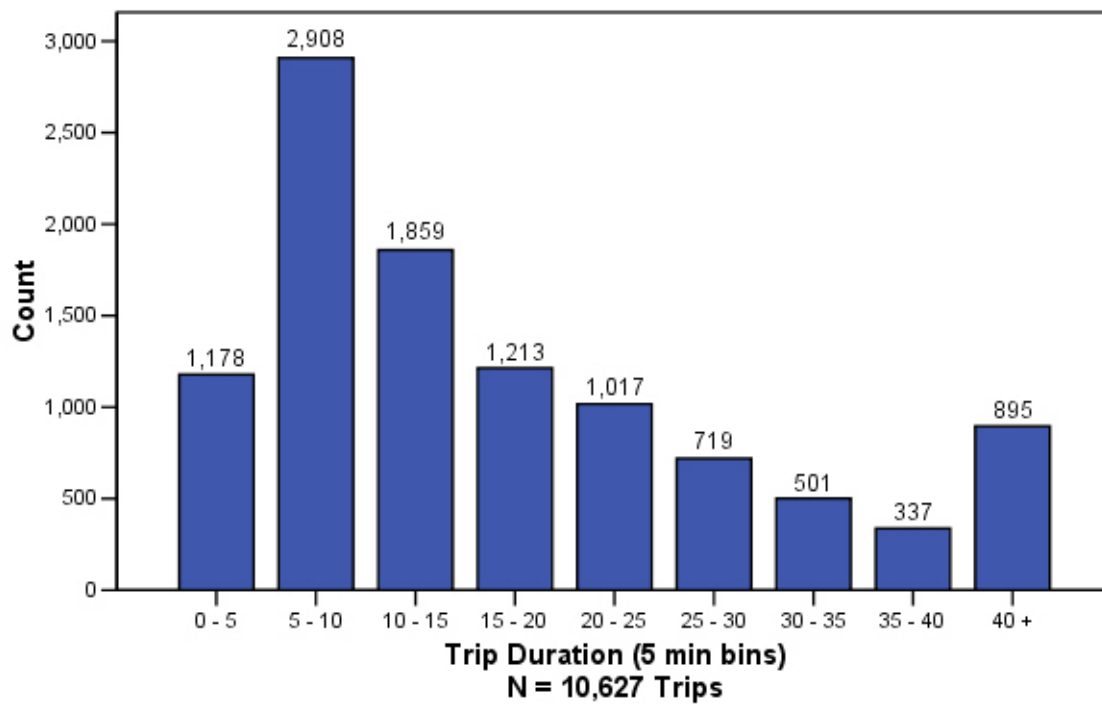


Figure 54 Distribution of Trip Duration (5 minute bins)

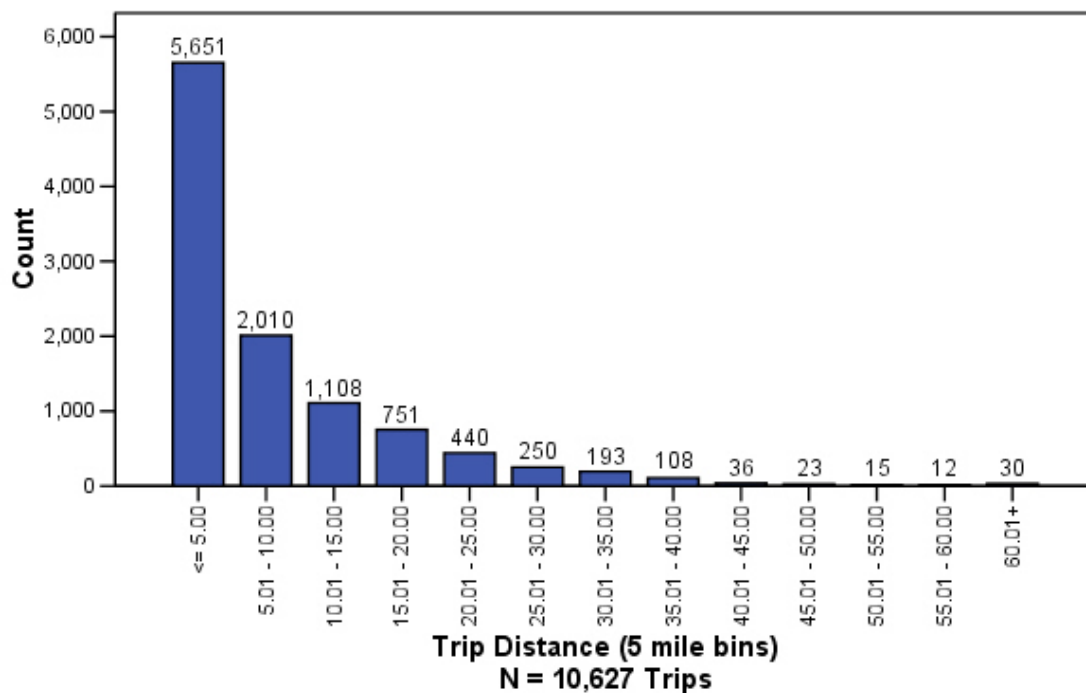


Figure 55 Distribution of Trip Distance (5 mile bins)

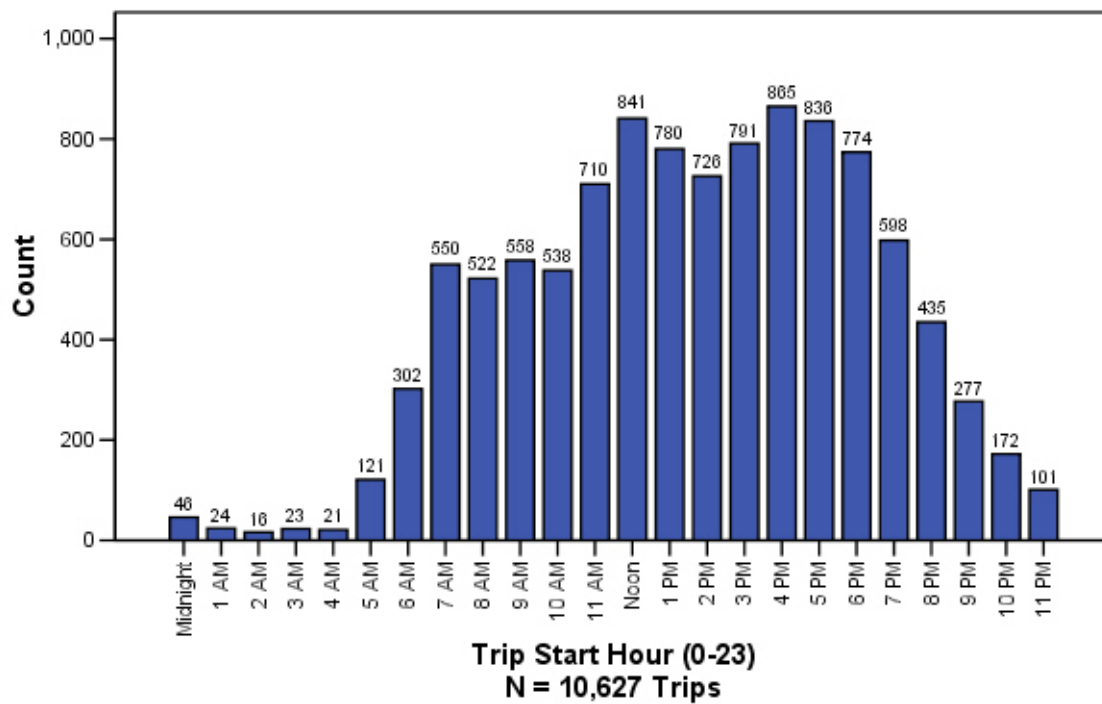


Figure 56 Distribution of Trips by Time of Day

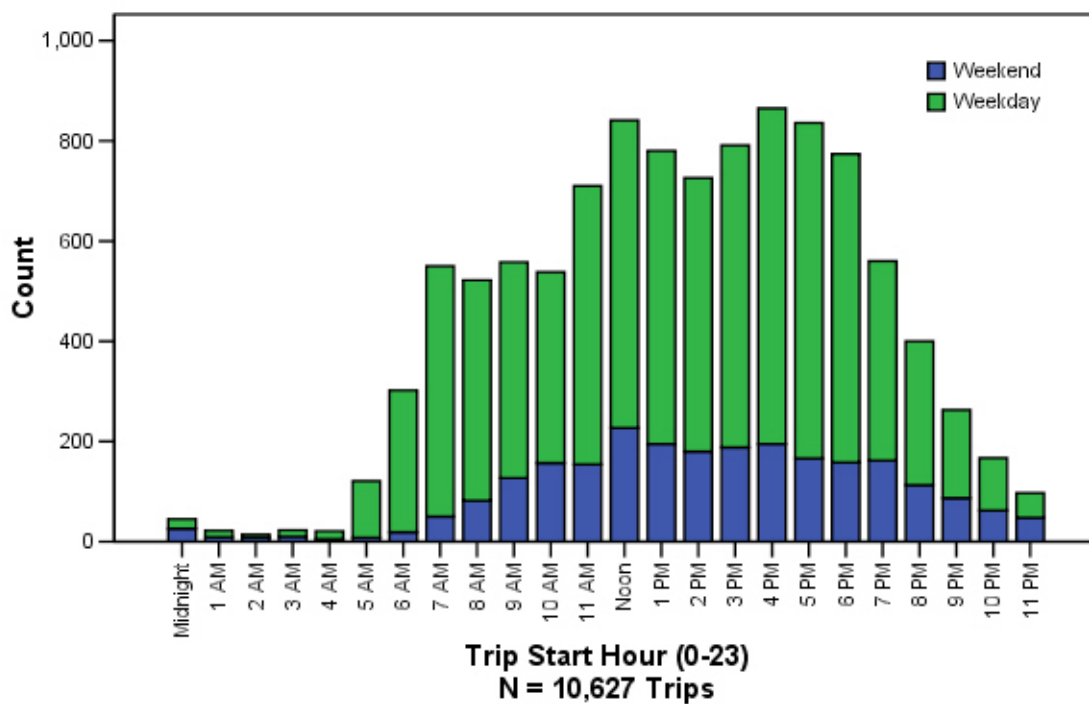


Figure 57 Distribution of Trips by Time of Day and Weekend/Weekday

Speeding Behavior Metrics

Three metrics were used extensively in this research. The metrics represent three elements of speeding behavior: amount, extent, and long-term trend. Each of the three metrics is described briefly as follows.

Amount

The amount of speeding is represented by the fraction of valid observations where the driver speed is greater than the posted speed limit divided by the total number of observations where the driver speed is greater than 5 mph. This value can be represented in multiple ways either using distributions by speed, or simply by percent of observations speeding over the posted speed limit. Figure 58 shows a speed distribution for driver 6279. Distributions can also be developed for individual trips.

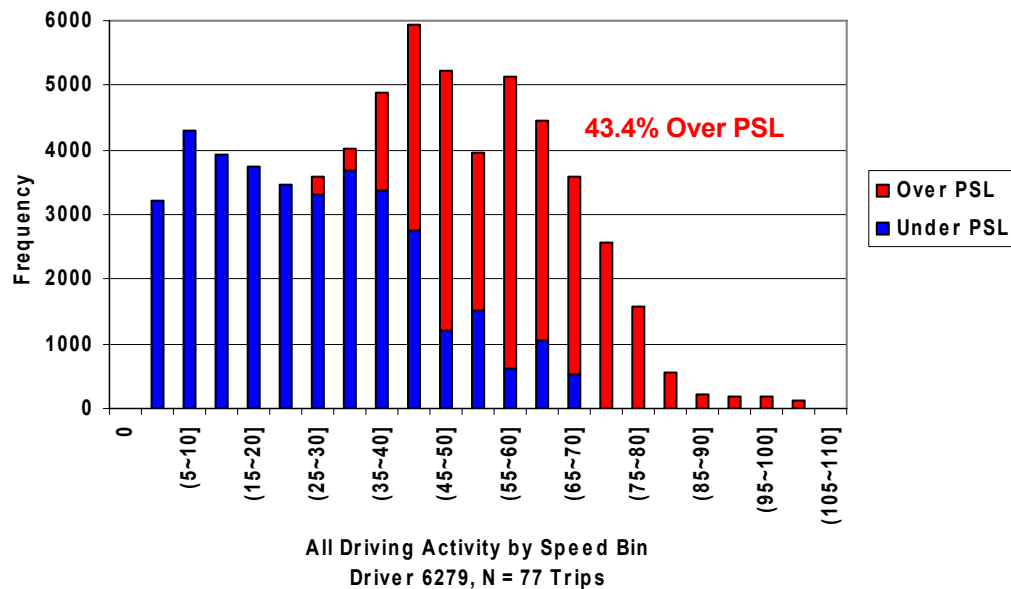


Figure 58 Total Amount of Speeding Activity for Driver 6279

Extent

The extent of speeding refers to the difference between the posted speed limit and the actual speed of the driver. A positive deviation from the posted speed limit represents driver speeding activity. A distribution of positive deviation from posted speed limit represents the extent to which a driver exceeds the posted speed limit. An example of such a distribution is shown in Figure 59.

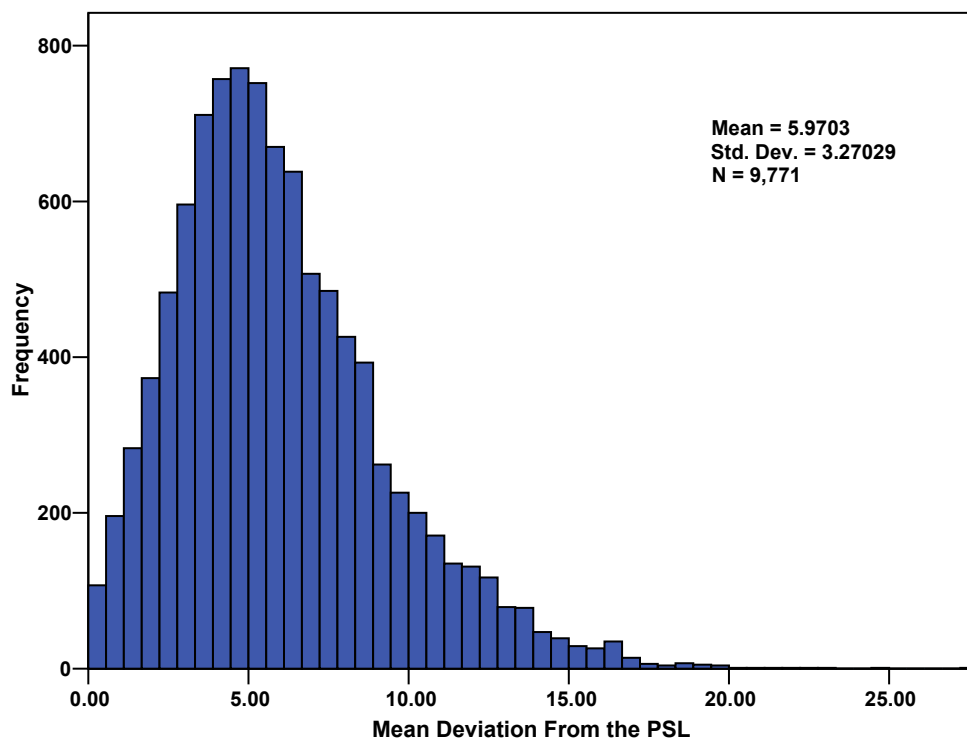


Figure 59 Distribution of Positive Deviation
Above the Posted Speed Limit

An average measure of the extent of speeding can be calculated for a trip or for a driver using the following equation.

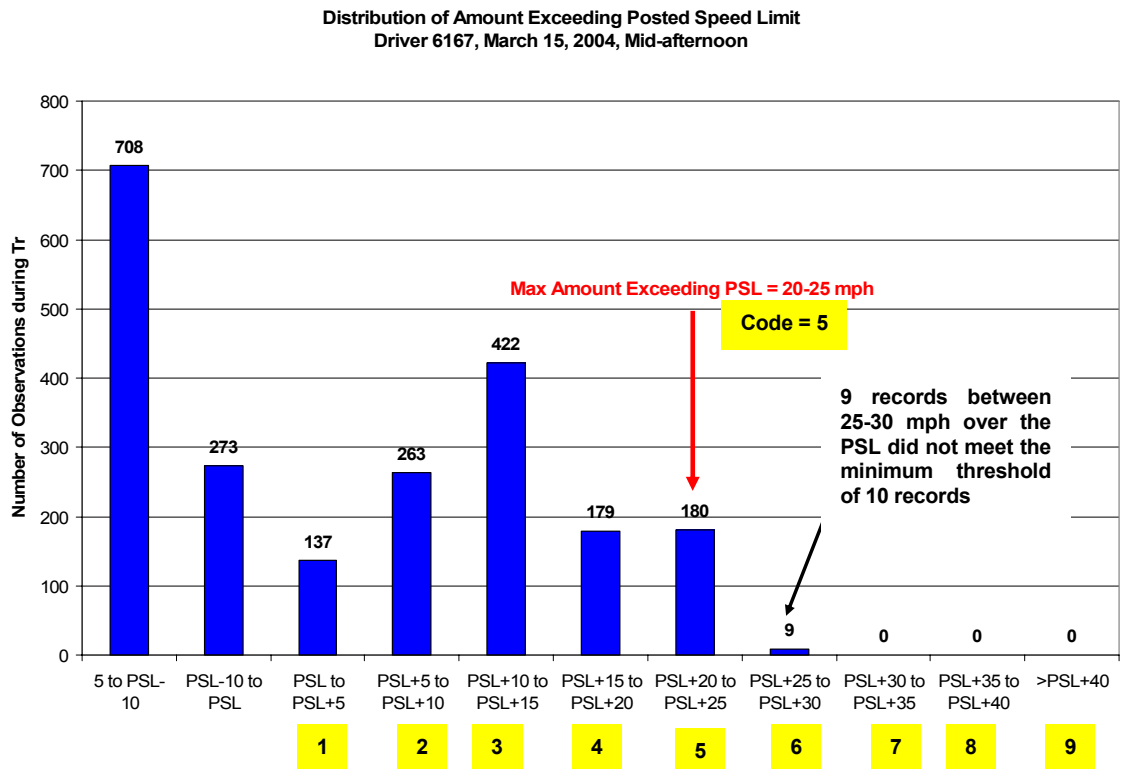
$$\text{Mean Positive Deviation from PSL} = \frac{\sum (\text{observed speed} - \text{PSL})}{(\text{total observations} > \text{PSL})}$$

Although the mean positive deviation from posted speed limit is a useful single metric tool for comparing drivers and trips, it loses the very important information about extreme speeding that is found in the slope and length of the tail depicted in the distribution of deviation from the posted speed limit. A mean positive deviation of 5.9 mph does not inform the analyst about the observations found in the tip of the tail where the deviation from posted speed limit was in excess of 20 mph. Another interesting use of this metric is to determine the mean deviation for different posted speed limits or functional classifications of roadways.

Long-term Trend

The third metric is derived from behavioral safety concepts. In behavioral safety programs, observers record samples of behavior observations noting whether they are performed safely or in an at-risk manner. Over a period of time, a *percent safe* score can be calculated by dividing the number of safe behavior observations by all behavior observations. A similar metric for speeding behavior might be represented by the percent speeding for each trip (e.g., amount metric), or percent speeding greater than xx mph above the posted speed limit for each trip. Likewise, the compliance metric may substitute individual observations within a trip with a single observation for the trip. For example, did the driver exceed the posted speed limit for more than 10 observations during the given trip? This metric requires some discussion about the potential to underestimate speeding using the percent speeding approach. Because the data are recorded on a standard 1-second time interval, more records will be recorded while

traveling a set distance at slower speeds than when traveling the same distance at faster speeds. For this reason, the use of a single observation for a trip provides a somewhat more objective picture of the long-term trends of speeding behavior. For example, the trip depicted in Figure 60 shows 180 records in the 20-25 mph deviation category, and 9 records in the 25-30 mph deviation category. Using a minimum number of records equal to 10 to satisfy coding requirements, the trip would be coded as a 5 indicating a maximum deviation of 20-25 mph above the posted speed limit for the trip. Using a sustained deviation threshold would further the legitimacy of this method in future research.



The application of the long-term trend metric requires a few assumptions to be made. The first assumption relates to the drivers' ability to choose his/her desired speed. When travel is constrained by the flow of surrounding vehicles, the driver is not free to choose his/her travel speed and therefore does not have the opportunity to exceed the speed limit if so desired. On the contrary, if the driving environment is unconstrained, the driver may choose to comply with the posted speed limits, or violate those limits. Therefore, only observations where the driver experienced unconstrained operations should be considered in the analysis. Specific car-following headways to support this specific assumption are lacking in the current dataset, and therefore a surrogate measure was adopted. The assumption follows then, that unconstrained travel occurs when speeds are in excess of the posted speed limit. Of the 10,627 valid trips considered in this analysis, 9,793 trips (92%) include observations above the posted speed limit.

Without knowing the exact relationship between the risk of crashing and speeding behavior, it is difficult to define a 'safe' speed threshold. Many arguments can be made to justify 'safe' speeds based on design speeds, posted speed limits, and legislated limits for violations. Because behaviors are reinforced by consequences, it seems logical to use a threshold set about the legislated violation threshold. In Georgia, this threshold is equal to the posted speed limit plus an enforcement leniency of 10 mph. Therefore, the assumption follows that speeding behavior below the legislated violation threshold (PSL + 10 mph) is considered 'safe', or more appropriately termed 'compliant'.

The formula for calculating *percent compliant* is:

$$\% \text{ Compliant} = \frac{\# \text{ Trips where driver speed does not exceed PSL} + 10 \text{ mph}}{\# \text{ Trips with unconstrained operation}} (100)$$

Table 18 gives several examples of calculated compliance rates based on number of trips coded within each deviation category. Note that deviations less than 10 mph above the posted speed limit are considered compliant, whereas deviations greater than 10 mph above the posted speed limit are non-compliant. As shown driver 6279 has a compliance rate of 0.23 which is derived by dividing 18 compliant trips by 59 non-compliant trips.

Table 18 Calculated Compliance Rates based on
Number of Trips Coded within Each Deviation Category

Driver ID	PSL to PSL+5	PSL+5 to PSL+10	PSL+10 to PSL+15	PSL+15 to PSL+20	PSL+20 to PSL+25	PSL+25 to PSL+30	PSL+30 to PSL+35	PSL+35 to PSL+40	>PSL+40	Compliance Rate
6279	4	14	21	12	9	8	5	2	2	0.23
6281	8	5	22	10	14	14	5	2	3	0.16
6384	20	23	21	30	23	11	4	2	1	0.32
6308	25	15	18	12	23	7	6	1		0.37
6233	3	8	8	14	8	4	4			0.22
6321	2	7	16	9	11	6			1	0.17
6298	4	9	26	22	8					0.19
6552	4	21	17	4						0.54
6401	9	22	11							0.74
6331	31	6		1						0.97
6222	23	8	1							0.97
6431	13	2								1.00

Table 18 also shows the distribution of trips with extreme positive deviations from the posted speed limit. Driver 6279 recorded two trips where the posted speed limit was exceed by more than 40 mph. At a posted speed of 25 mph this would represent a chosen speed of at least 65 mph, however, at a posted speed of 55 mph this deviation represents a minimum of 95 mph. On the opposite end of the spectrum, driver 6431 did not record

any non-compliant trips. This is the only driver out of the sample of 172 drivers to maintain 100% compliance with the legislated violation threshold.

Speeding Behavior Descriptive Statistics

From the literature, one of the most universally supported relationships with respect to speeding behavior is that between the age of the driver and speeding. Figure 61 and Figure 62 both capture the amount of speeding by the age group of the driver. As with previous research, both error bar charts depict trends of decreasing speed with increasing age. The young driver group is also shown as the group with the largest percentage of their driving time spent above the posted speed limit. The difference between the two figures is the aggregation level of the data. Figure 61 provides the mean amount of speeding over all trips for the age group. Therefore, the mean is potentially influenced more by one driver than another because the trips are made by repeated drivers, and some drivers make more trips than others. Figure 62 represents the average of the mean amount of speeding by driver thus giving the same weight to all drivers.

The trends are very similar; however, the smaller sample size represented in the driver averages tends to yield greater variability about the mean. The same trend found in previous research is also apparent in these two figures. Young drivers participate in speeding behavior at a greater rate than older drivers, and there is a decreasing trend of speeding as age increases. The young driver age group also has the highest mean amount of speeding of all the age groups. Note that the sample of young male drivers is incomplete (7 instead of 15), therefore, the average amount of speeding for this group could be higher or lower than shown. As noted earlier, if it were possible to decrease the amount of

speeding behavior of the young driver group, the trend may continue with the aging process, and overall speeding behavior might be reduced. It is clear that the preference for speeding is developed at an early age.

Another common relationship is that of driver gender and speeding. The male gender is more commonly associated with speeding behavior. Males tend to be overrepresented in the number of citations received as well as the amount and extent of speeding. However, based on the total sample for this research, there is not a statistically significant distinction in the speeding behavior of males versus females (see Figure 63). Further analysis of this relationship is shown in Figure 64 and includes the effects of driver age and gender. For drivers age 25-44, there are significant differences in the average amount of speeding for males and females. In the young driver group, males and females participated in speeding at nearly equal amounts. Again, it is important to note that the young male driver sample is small and therefore, the representative amount of speeding may be underestimated. One distinct difference in driver speeding behavior between genders occurs in the 45-54 age group, where females are shown to have a higher amount of speeding than males. Reasons for this anomaly are unknown.

The income level of the driver has also been previously associated with speeding behavior. Unfortunately, the Commute Atlanta data set does not provide income by person, but at the household level. Therefore, young drivers that are still living with their parents are listed as having the income of the household. This designation is somewhat misleading. Nonetheless, this is currently the best data available for this analysis. Subsequent household surveys may attempt to collect this data at the individual level.

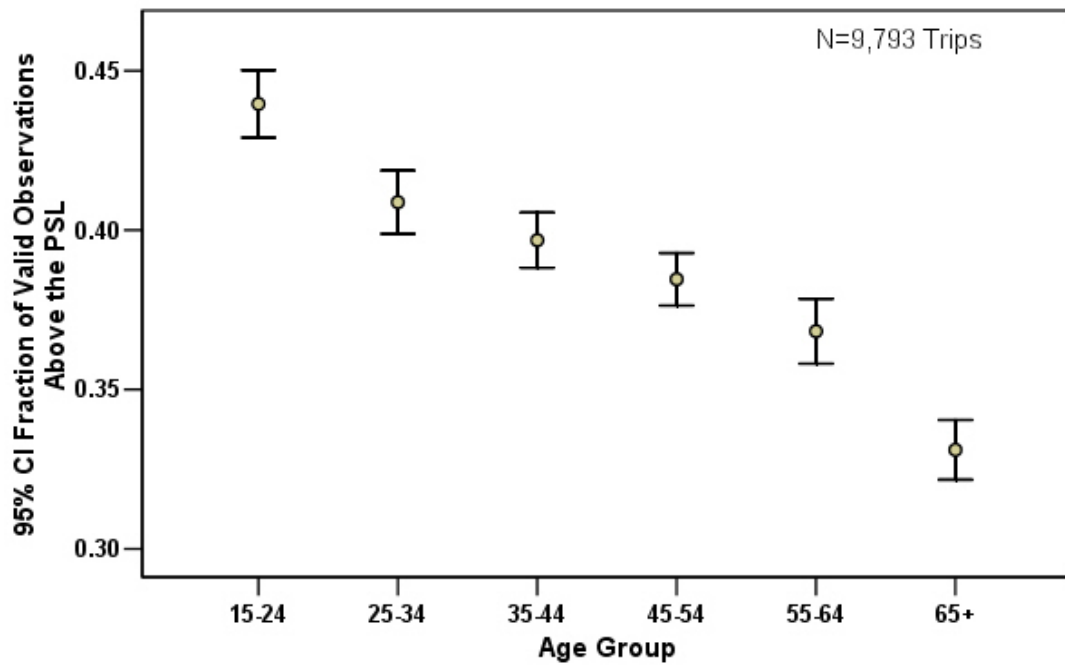


Figure 61 Amount of Speeding (Trips by Repeated Drivers) by Age Group

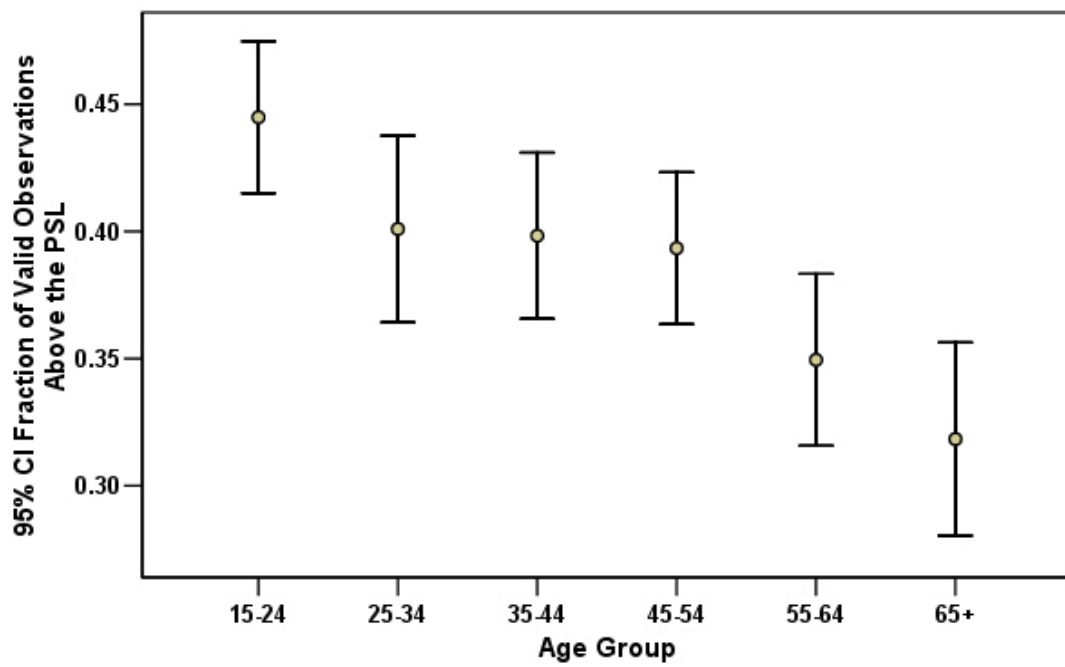


Figure 62 Amount of Speeding (Driver Average, N = 172) by Age Group

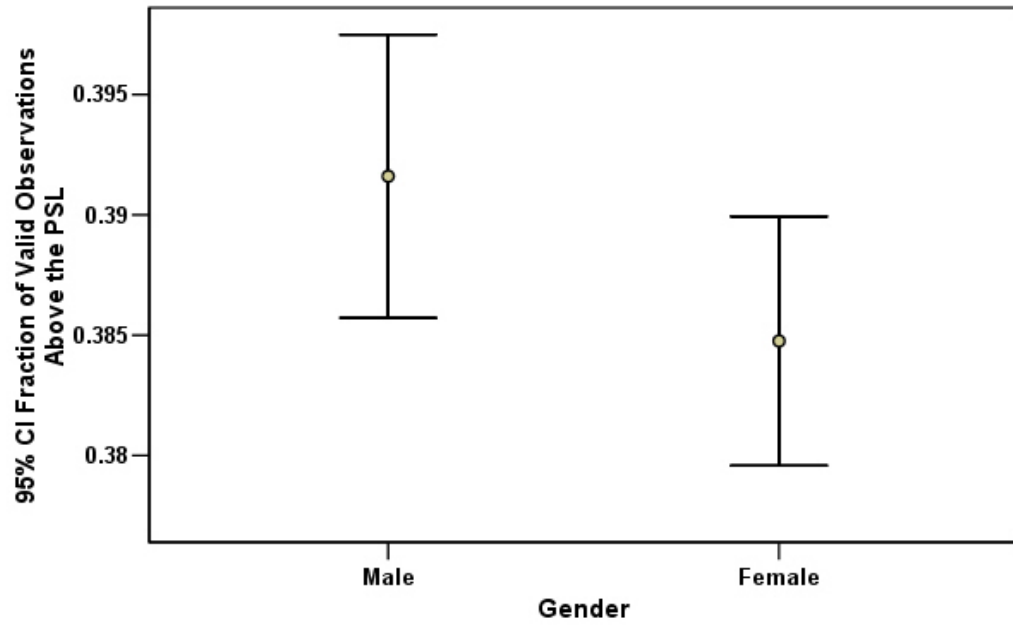


Figure 63 Amount of Speeding by Gender

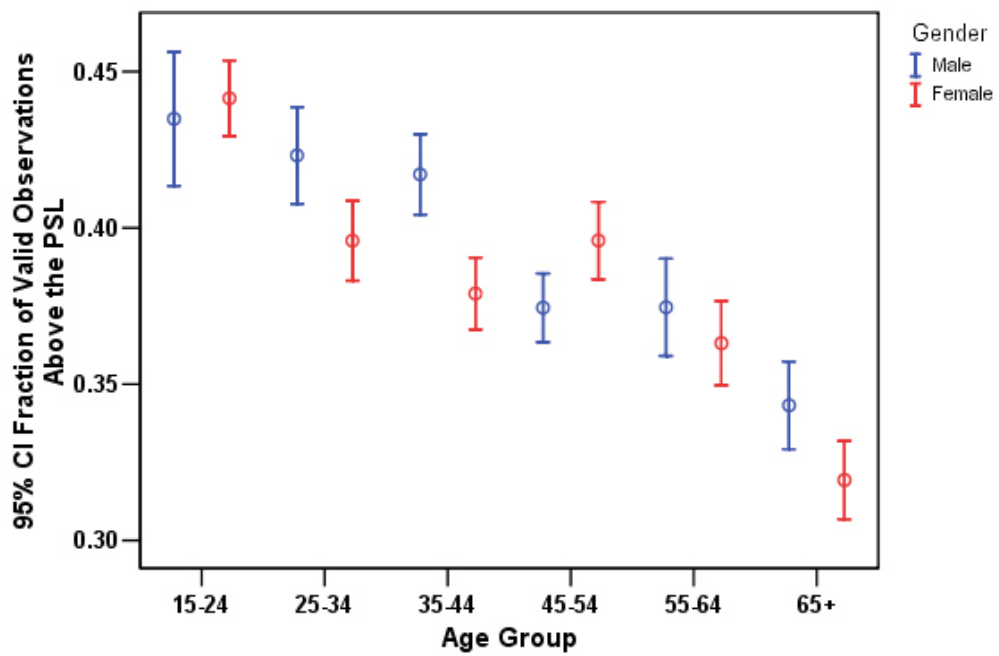


Figure 64 Amount of Speeding by Age and Gender

Figure 65 shows the amount of speeding greater than 10 mph above the posted speed limit by household income level. At best, only a weak relationship exists between speeding in this sample and income level.

Given the issue of the young driver associated with the parents' income, researchers reviewed the data for age and income correlations. The majority of the young drivers were associated with the top five income levels, whereas the older drivers (> 65) held a majority of lower income designations. A second error bar chart (Figure 66) was produced after removing the influence of these two groups. The resulting relationship does not show the trend of the first graph. Additionally, the limited number of lower income households in this sample increases the variability in these groups and limits the ability to make strong statements about speeding and income. A recommendation for future studies would be to have a sample representative of age, gender, and income.

The last two figures (Figure 67 and Figure 68) associated with the amount of speeding refer to trip characteristics of duration and distance. Figure 67 shows an positive relationship of speed with duration. As trip duration increases, so too does the amount of speeding. With shorter trips, only about 30% of the trip on average is above the posted speed limit. On longer duration trips around 25-30 minutes in length, the amount of speeding goes up to almost 50% and then begins to level off or drop slightly with longer durations. Note that this error bar chart includes operations on all types of facilities under varying traffic conditions.

A similar relationship exists between the amount of speeding during a trip and the trip length (see Figure 68). Trips less than 5 miles in length have about a third of the

observations over the posted speed limit. On average, the majority (57%) of valid observations on trips 20 - 25 miles in length are above the posted speed limit. On long trips (> 40 miles), between 60 and 70% of the observations on average are above the posted speed limit.

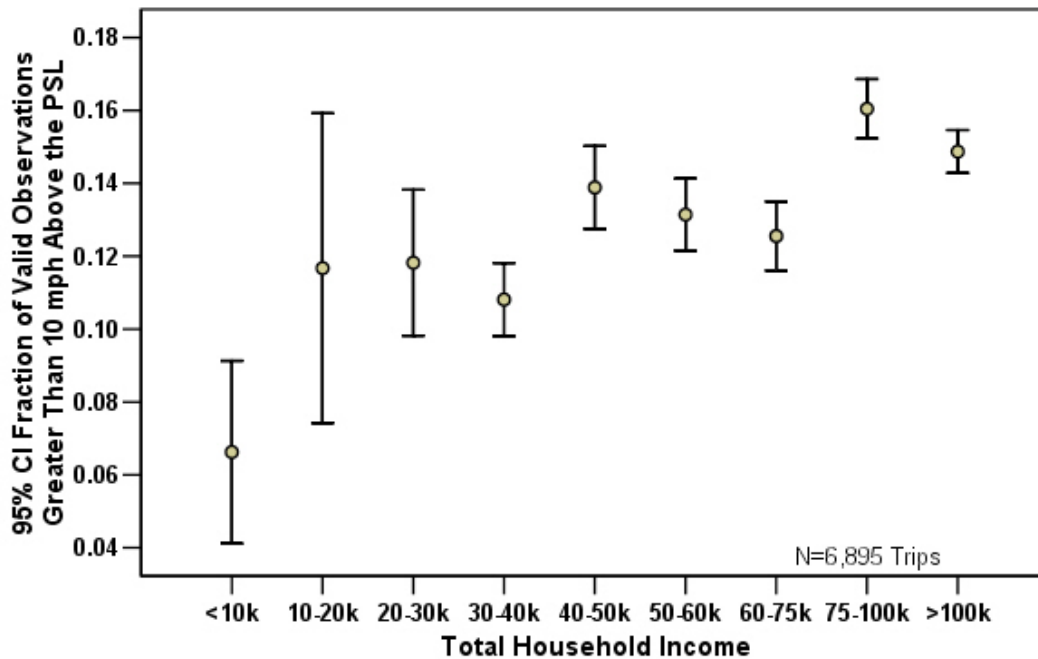


Figure 65 Amount of Speeding (> 10 mph Above PSL) by Household Income Level

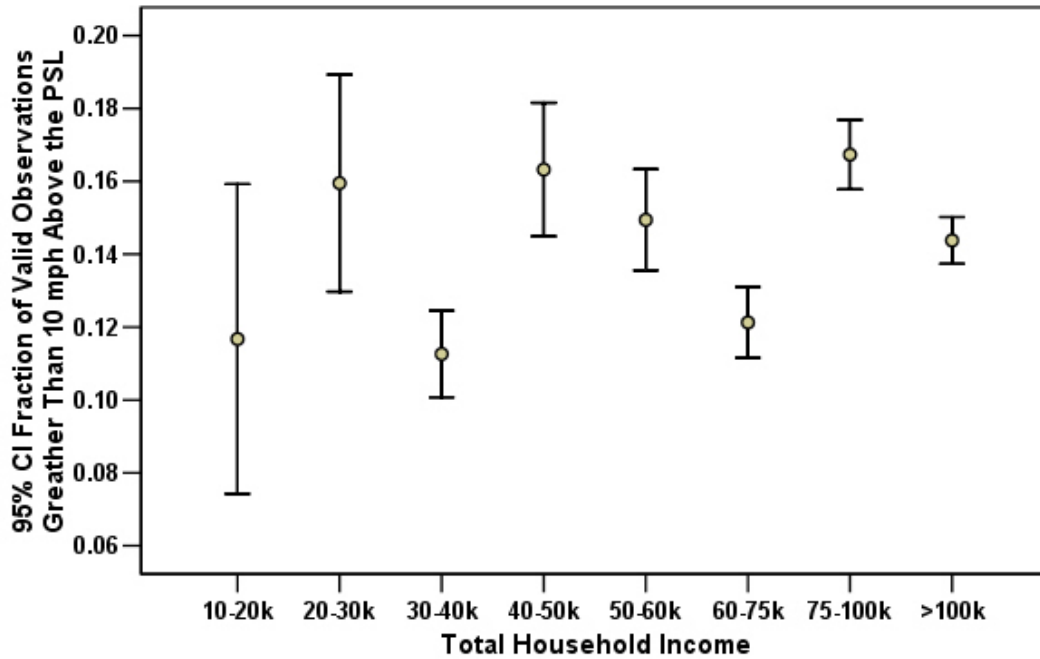


Figure 66 Amount of Speeding (> 10 mph Above PSL) by Household Income Level (Ages 25-64 only)

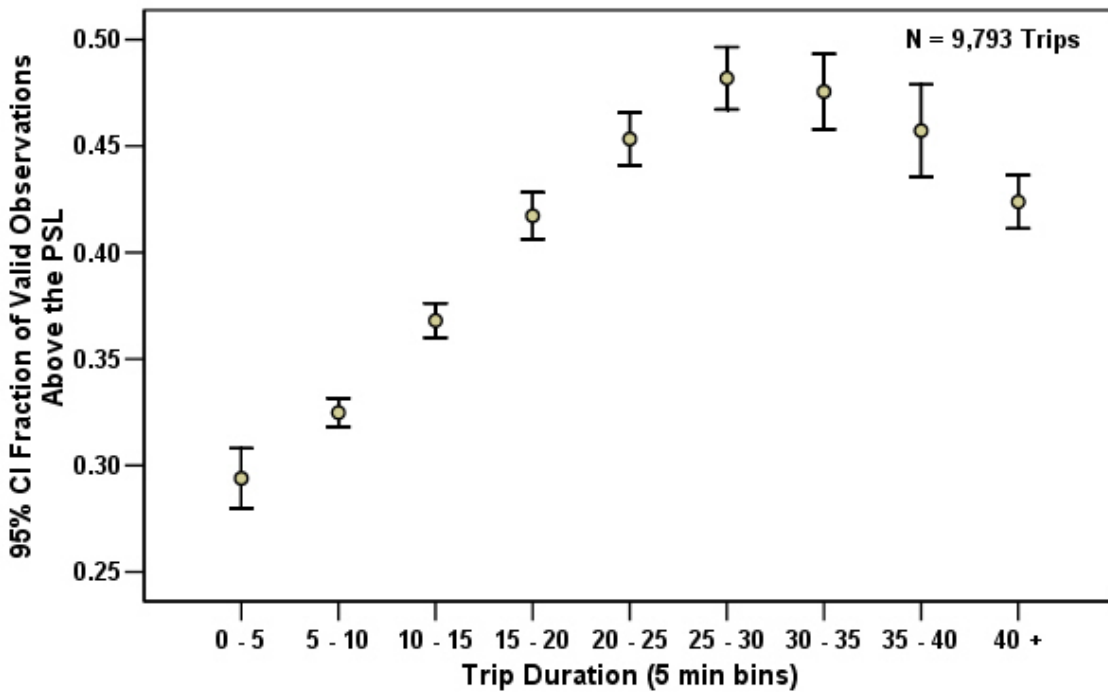


Figure 67 Amount of Speeding by Trip Duration

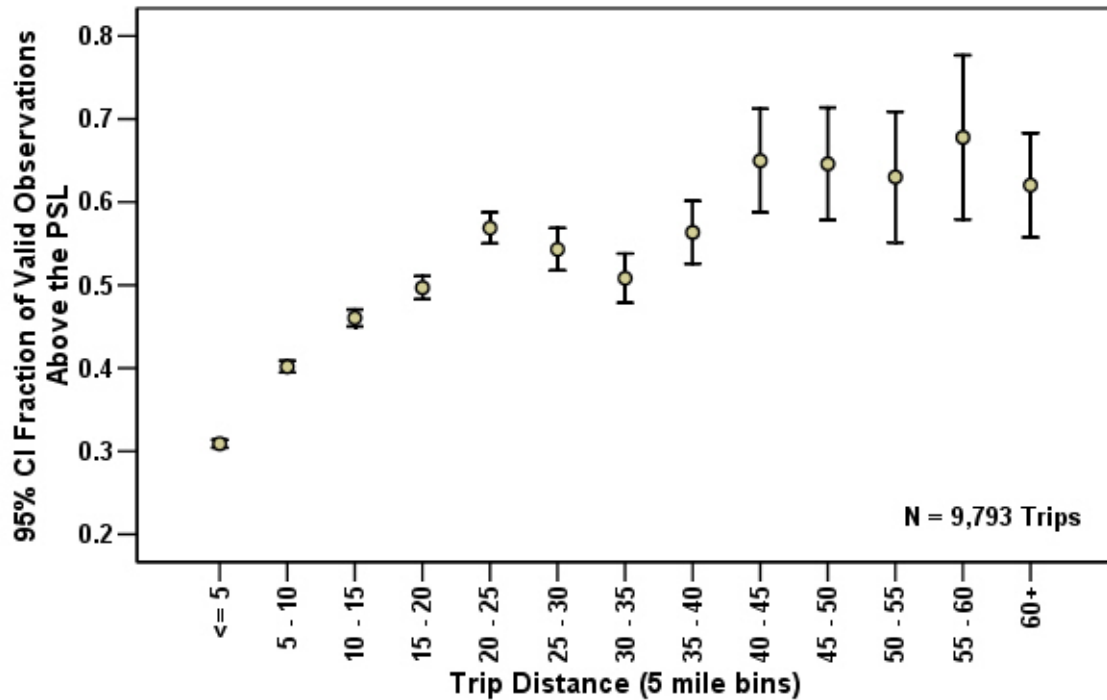


Figure 68 Amount of Speeding by Trip Distance

All of the previous graphs dealt with the amount of speeding metric. The following graphs are based on the mean positive deviation from the posted speed limit which relates to the general extent of speeding behavior. The mean positive deviation is given in miles per hour. As with the amount of speeding, a similar relationship exists between driver age and the extent of speed above the posted speed limit. Young drivers not only spend more time speeding, but they are also speeding at greater extents above the posted speed limit than other age groups. As with the amount of speeding, there is a decreasing trend in the extent of speeding as age increases. Drivers age 15-34 have the highest mean positive deviation above the posted speed limit. If the sample of young male drivers were larger, the mean positive deviation for this group might potentially be higher. Given the trend of decreasing positive deviation with increasing age, lowering the level of deviation among

young drivers may affect the overall trend. Similar trends were found for mean positive deviation and other factors as were found for the amount of speeding shown earlier. The general trend for mean positive deviation shows that those who speed a lot do so at higher speeds.

The last metric is related to the long-term trend and indicates the compliance with legislated speed enforcement levels (posted speed limit + 10 mph) by trip. In this case, trips are coded by the maximum deviation above the posted speed limit occurring for more than ten observations throughout the trip. Figure 71 shows the average compliance rate by age group and gender. Younger drivers tend to have lower compliance rates than older drivers, and gender differences are insignificant. Although not statistically significant from one group to the next, the trend suggests that compliance increases with age.

On average if the drivers' compliance rate is low, it seems reasonable to expect these drivers to have a higher incidence of speeding citations. This theory was tested using self-reported citation data from the last five years. 89 drivers in the sample completed the participant survey. Overall, 20 drivers indicated having received citations for speeding in the last five years. 16 drivers with compliance rates below the 50th percentile of compliance have received one or more speeding tickets in the last five years. Only 4 drivers in the upper 50th percentile of speed compliance have received speeding citations. Using a relative risk ratio, drivers above and below the 50th percentile compliance rate (49 and 40 cases respectively) were compared in regard to receipt of citations. The relative risk of receiving a citation was almost 5 times higher for drivers with lower levels of compliance than for drivers with higher levels of compliance. This result was expected.

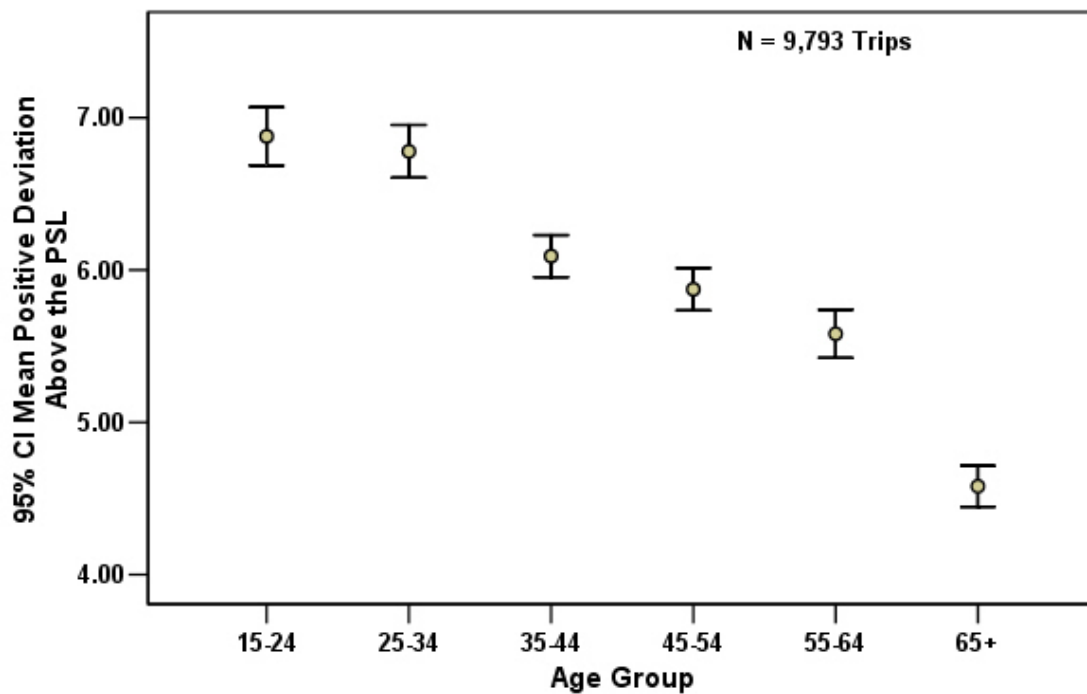


Figure 69 Extent of Speeding by Age Group (Trips by Repeat Drivers)

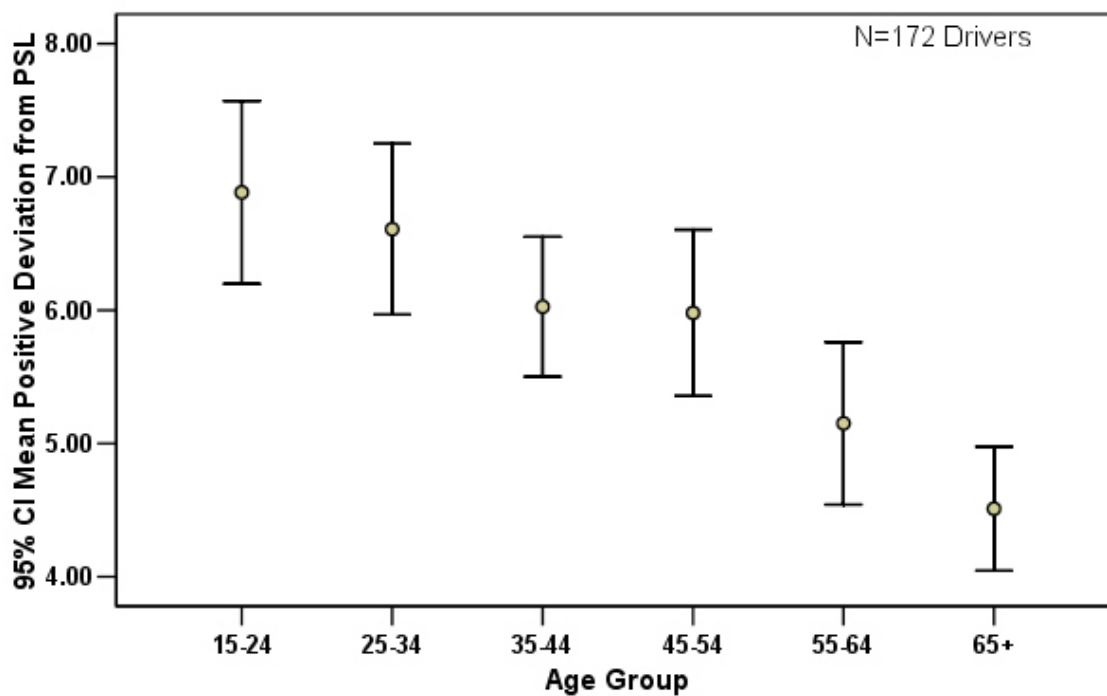


Figure 70 Extent of Speeding by Age Group (Driver Average, N=172)

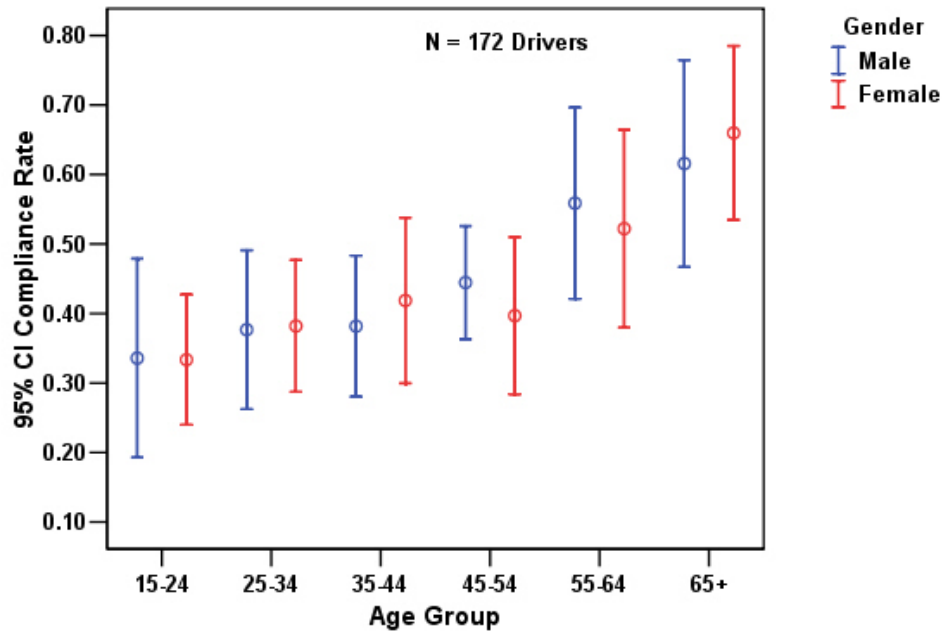


Figure 71 Compliance Rate by Age and Gender

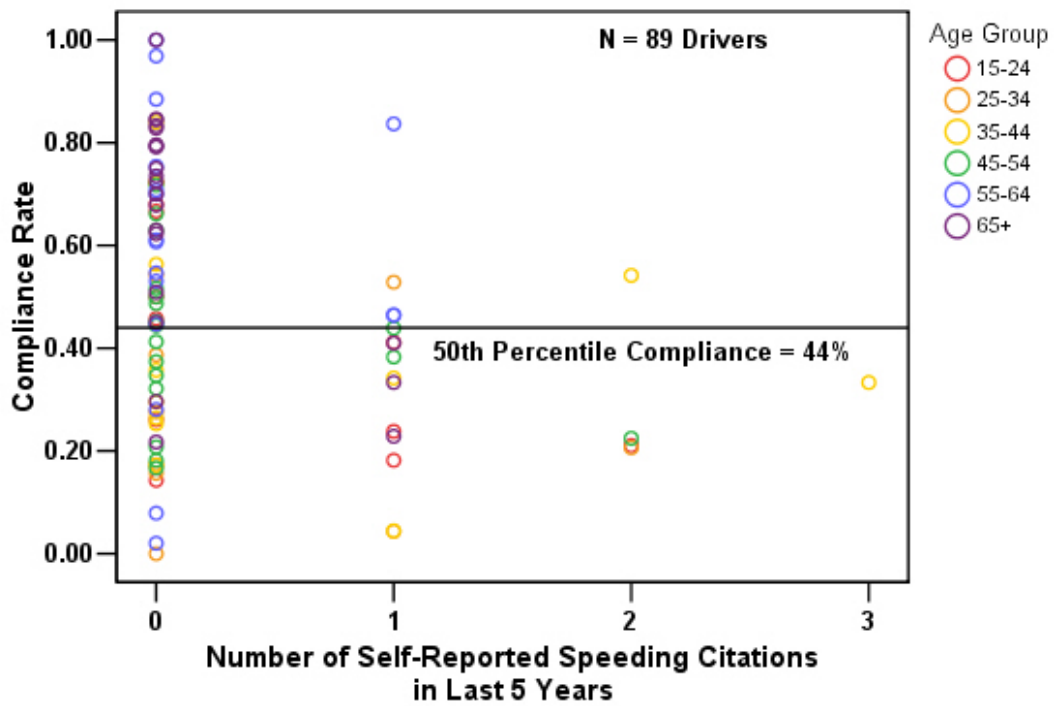


Figure 72 Compliance Rate versus Self-Reported Citations Last 5 Years

Case Studies

The previous section portrayed general trends regarding speeding behavior by age, gender, income, and trip characteristics. However, these general descriptive statistics do not capture the true patterns of speeding relative to the individual driver. For this reason, six case study drivers were selected to display the differences in speeding behavior by time of day and day of week, as well as other socio-demographic characteristics. Graphics and tables from the first case study have been used previously in the document (Figure 53, Figure 58, and Table 18). This participant is a male, between 15 and 19, who is living with his parents. He drives an older compact car. During the 16-day study period, he drove 847 miles and made 77 individual trips. He did not complete the participant survey, so there is no crash or citation data available. Figure 73 shows the drivers' compliance rate in comparison to standard percentiles of compliance. His compliance rate lies within the 10th to 20th percentile and has a compliance rate of 0.234 (or 23.4%). Overall, 44% of his driving activity is above the posted speed limit. This driver was chosen to show the extreme extent of speeding within the population. Figure 74 indicates the number of trips coded into each speed deviation category by trip start hour. This individual has a number of trips with deviations above the posted speed limit of 30 mph, and two trips with deviations over 40 mph. Further, the 40+ mph deviations occurred later in the evening after 8 PM and 10 PM. When queried by day of week instead of trip start hour (Figure 75), the max trip deviations indicate these excessive speeds occur on the weekend during the late evening. A sample of this 'joy-riding' activity is shown in Figure 76. The map shows driver speeds in excess of 100 mph along a section of interstate freeway where the posted

speed limit is 55 mph. This is the type of speeding behavior that should be identified and modified.

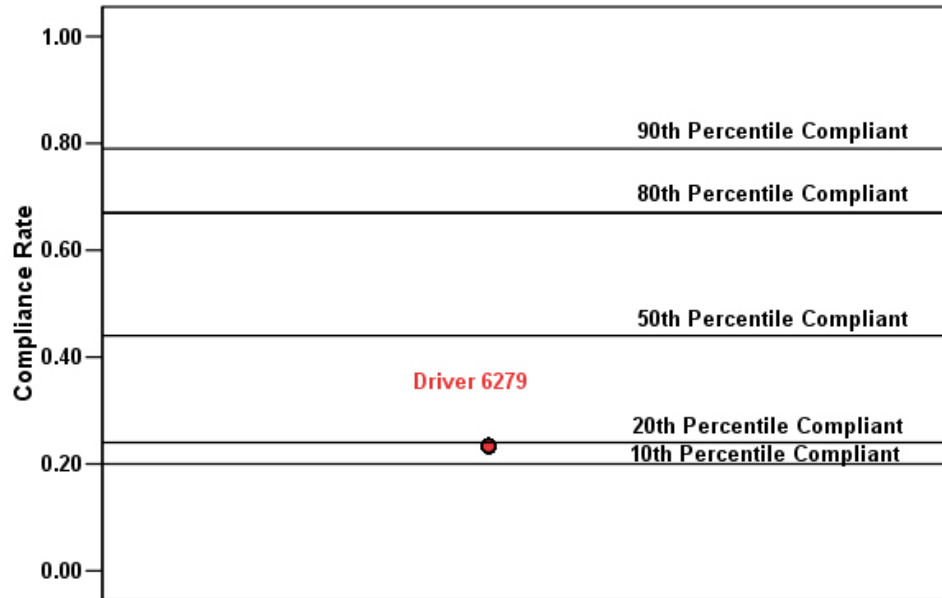


Figure 73 Compliance Rate - Driver 6279

The second case study is a female, age 15-19, who also lives with her parents and attends high school. The income level of the household is also \$75,000-\$100,000. She drives a late model sporty sedan. During the 16-day period, she drove 343 miles and made 47 trips. She has a compliance rate of 26%, and 52% of her activity is over the limit. Her mean deviation above the posted speed limit is 8.8 mph. Unlike the previous young male driver, the majority of her trips with high speed deviations occur in the early morning hours during the weekday (Figure 77 and Figure 78) – indicating that these are school trips. Only three trips were made on the weekends, and none had these most extreme speed deviations. She indicated on the participant survey that she had been involved in one crash during her first year of driving.

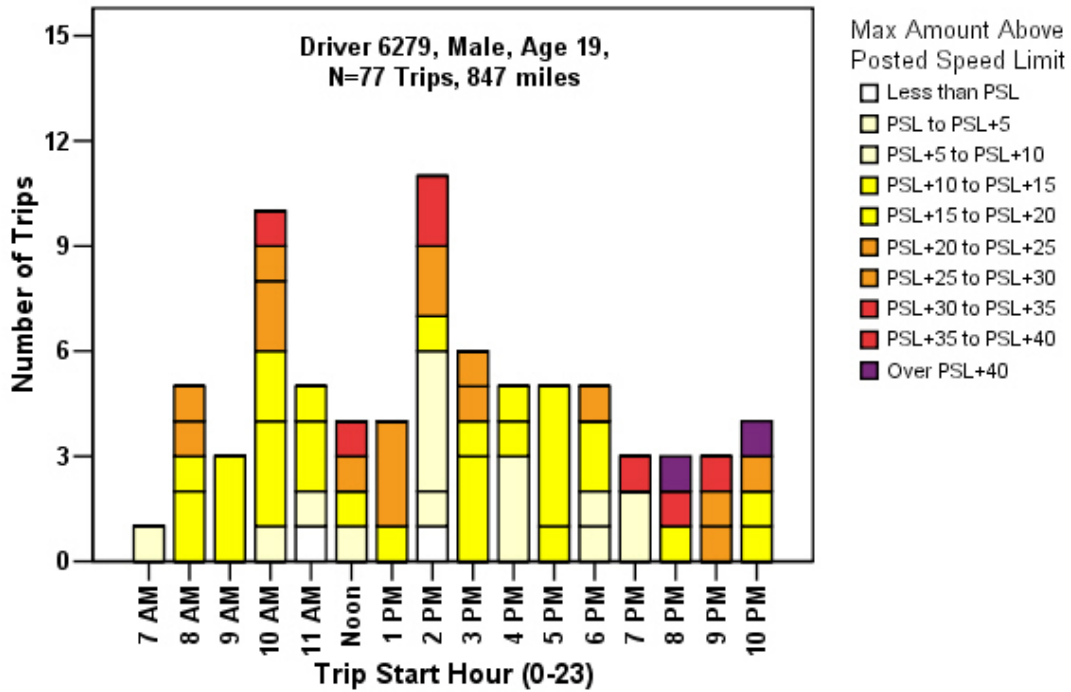


Figure 74 Trip Deviation Above the PSL by Trip Start Hour – Driver 6279

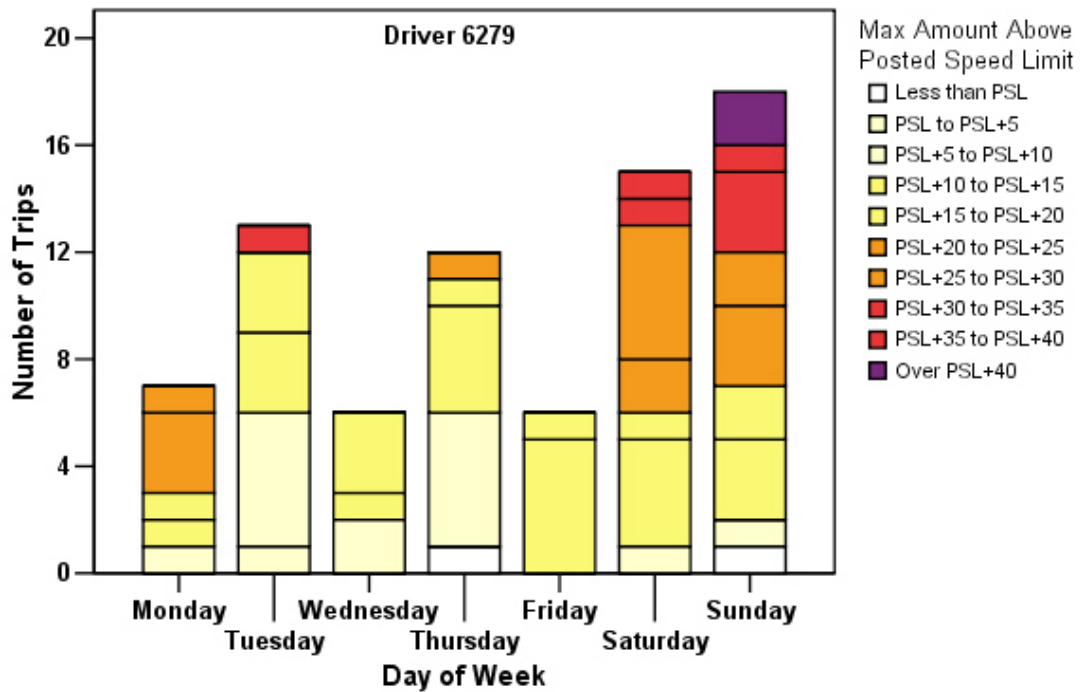


Figure 75 Trip Deviation Above the PSL by Day of Week - Driver 6279

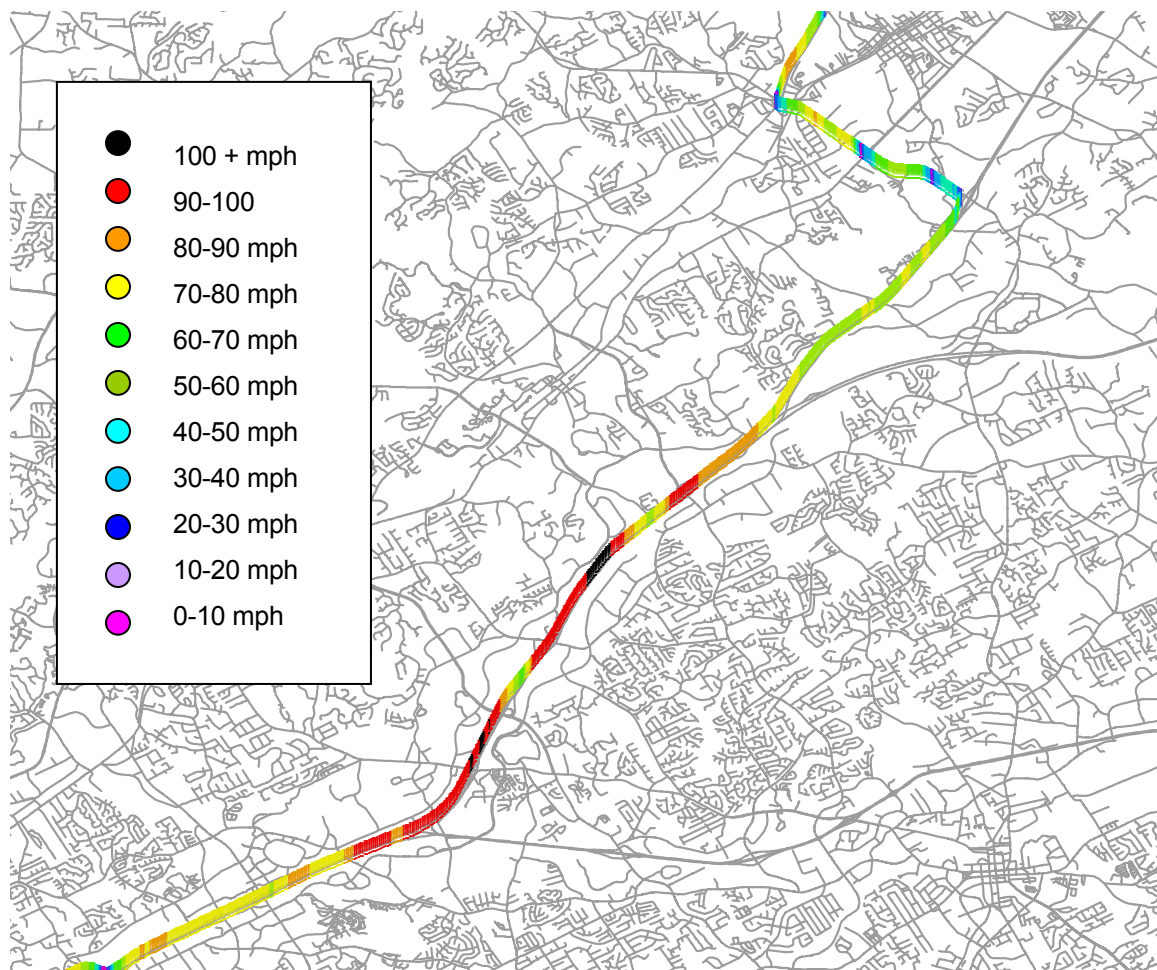


Figure 76 Second-by-second Speed vs. Posted Speed Limit (Driver 6279)

The third case study is a male, age 44-49. This participant is married and has a child. He works full-time and listed his occupation as professional with a graduate degree. The total household income is in the range of \$75,000 to \$100,000. The participant drives a mid-sized sport utility vehicle that is a few years old. During the 16-day study period, this participant drove 648 miles and made 84 trips. He received his license at age 15, and over his lifetime he has had 5 crashes, with one occurring during the study period. He indicated that he was at-fault in 3 out of 5 crashes, and one included injuries. He has also had 2 speeding tickets in his lifetime. Although this driver does not have any trips with

deviations of 40+ mph over the speed limit, he has a number of trips with deviations of more than 20 mph and one over 30 mph. The proportion of trips with non-compliance with legislated enforcement limits is such that he too has a compliance rate of 25%. Approximately one-third of his driving activity is above the posted speed limit, and he has a mean positive deviation above the posted speed limit of 6.7 mph. Figure 79 and Figure 80 show the overall trip deviations by trip start hour and day of week. Driver 6131 has a very regular pattern of speeding and trip making. The largest deviations occur during the morning commute, showing similarity to the second case on her morning school commute.

Case study number four (Driver 6186) is a female, age 44-49, who is married with no children. She works full-time in a sales/service occupation, and she completed an undergraduate education. She too has a total household income in the range of \$75,000 to \$100,000. The participant drives a minivan that is only a few years old. She has been driving for 35 years and has never received a speeding citation. However, she has been involved in 3 crashes in her lifetime, and has been at-fault for all 3. One of the three crashes occurred during the study period. The mean deviation above the posted speed limit for this driver is 4.2 mph, and 27% of her activity is above the posted speed limit. Driver 6186 has a compliance rate of 71.7%. Figure 81 and Figure 82 portray this driver as a generally modest driver, but with two trips indicating extreme 40+ mph deviations above the posted speed limit. The majority of her moderate to extreme speeding behavior occurs in the mid-to late afternoon from Friday to Sunday. An important distinction to make in analyzing the relationship between speeding and crash risk is whether the participant is a regular extreme speeder, or a moderate speeder with a few exceptional speed trips. These types of trips may be more prone to crash involvement.

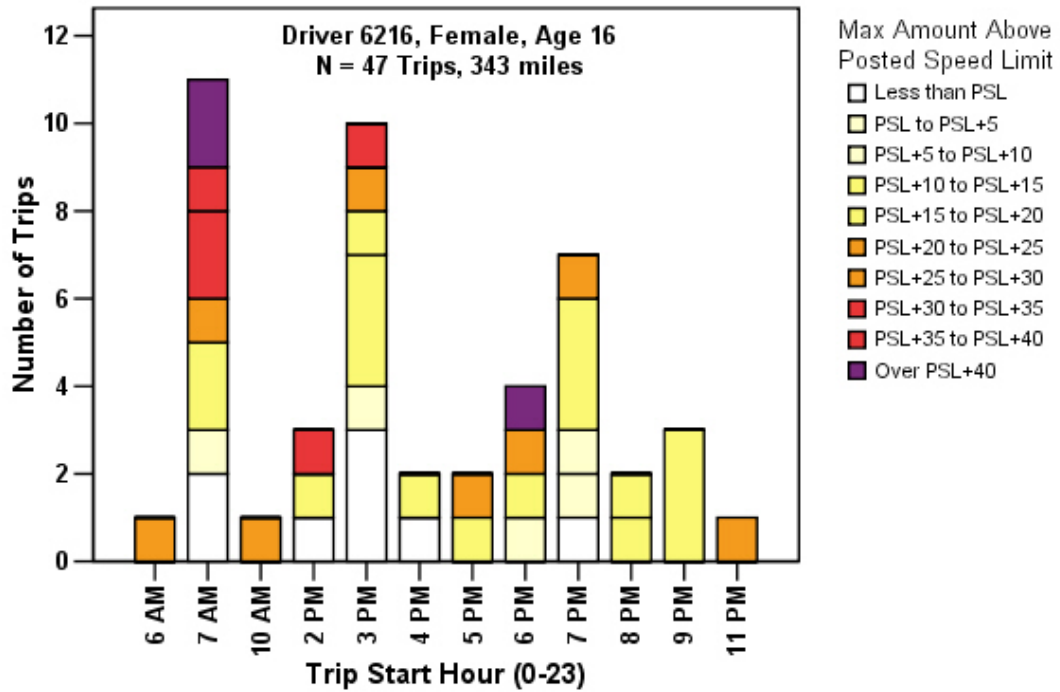


Figure 77 Trip Deviation Above the PSL by Trip Start Hour - Driver 6216

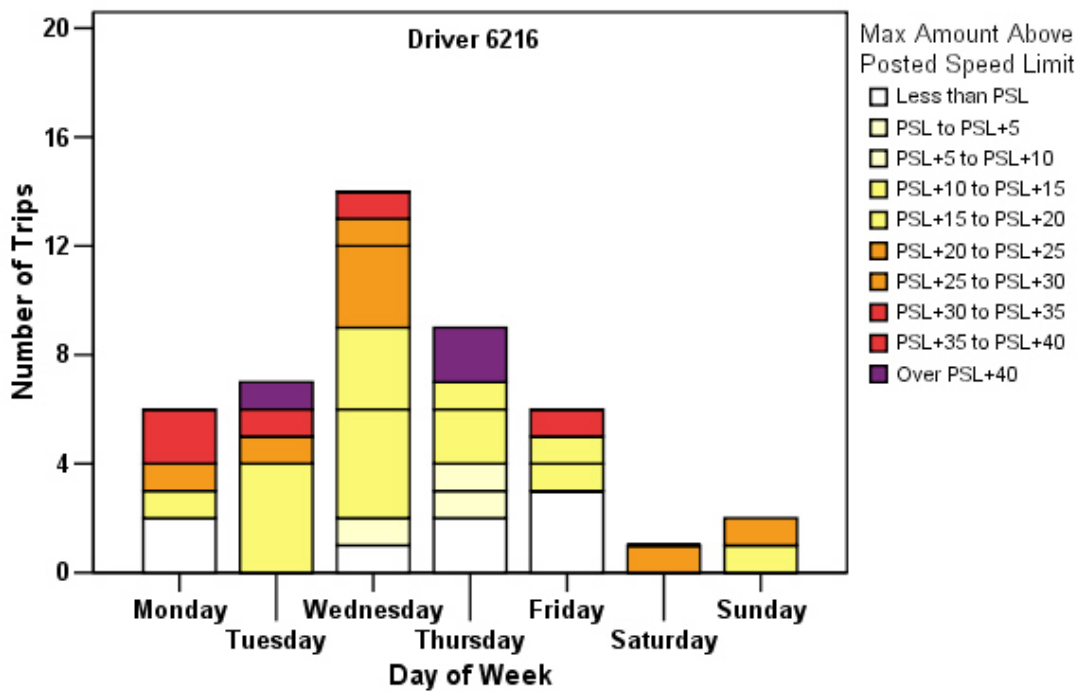


Figure 78 Trip Deviation Above the PSL by Day of Week - Driver 6216

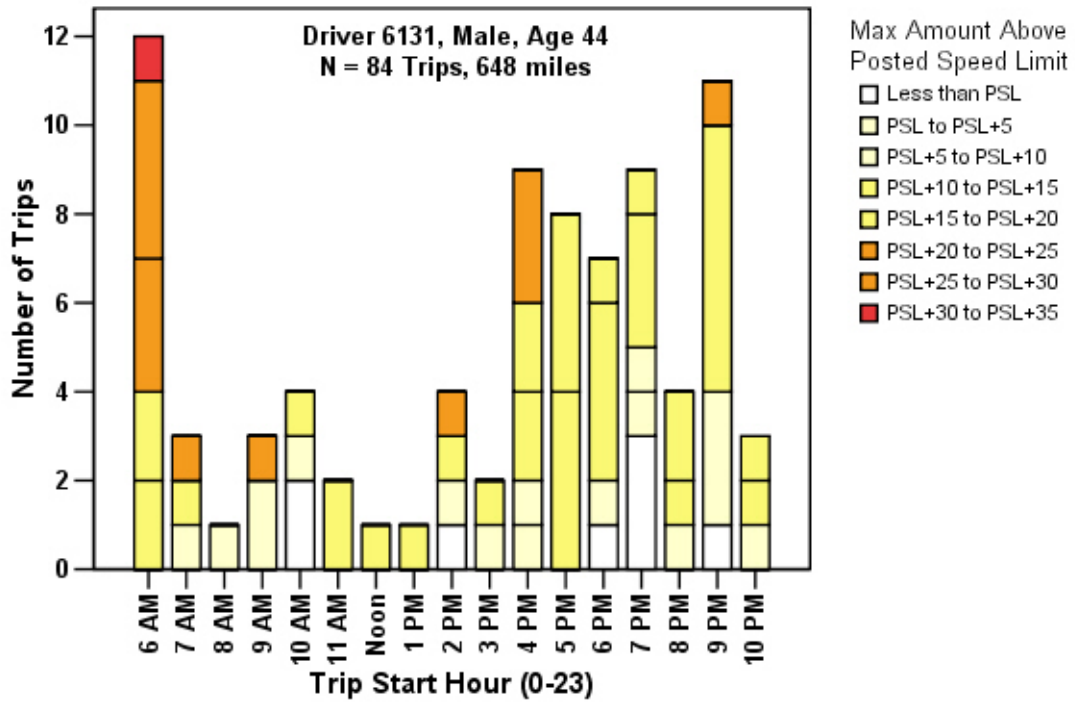


Figure 79 Trip Deviation Above the PSL by Trip Start Hour - Driver 6131

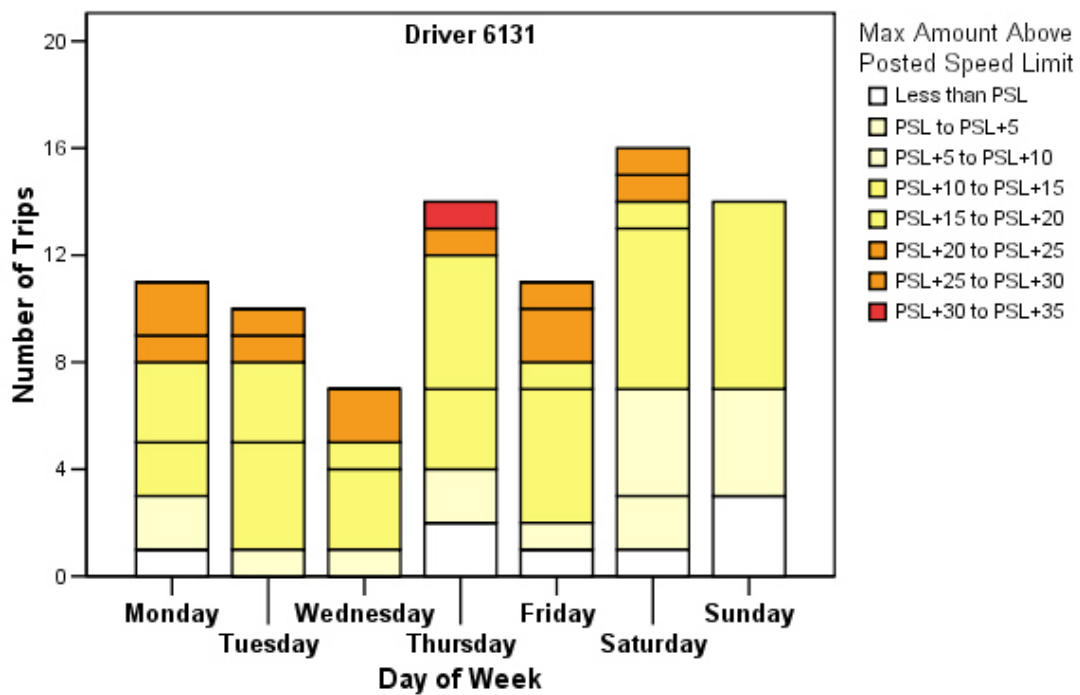


Figure 80 Trip Deviation Above the PSL by Day of Week - Driver 6131

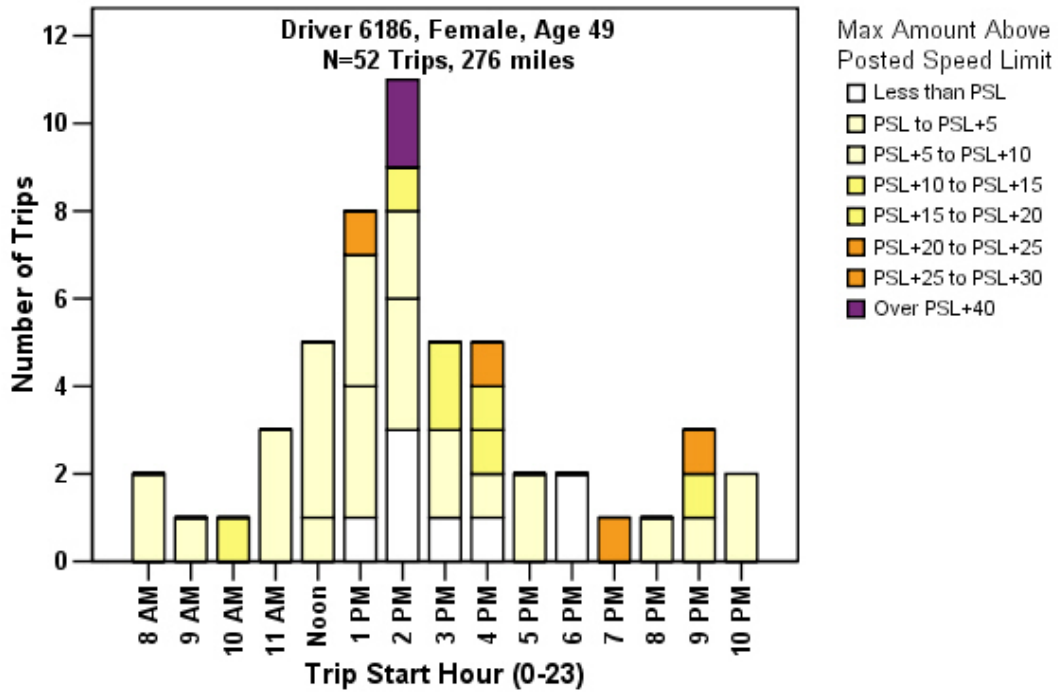


Figure 81 Trip Deviation Above the PSL by Trip Start Hour - Driver 6186

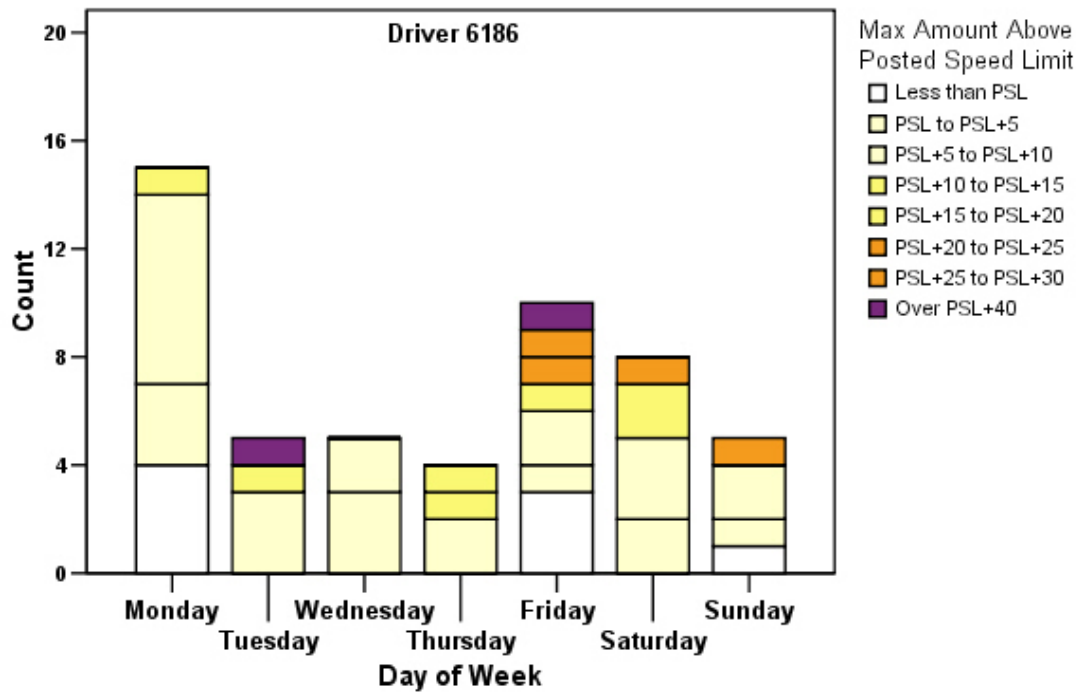


Figure 82 Trip Deviation Above the PSL by Day of Week - Driver 6186

The fifth case study driver is another female, age 15-19. She is a high-school student and lives with one parent. The total household income is between \$50,000 and \$60,000. This participant drives a compact car with model year between 1995 and 2000. She completed the participant survey and indicated that she had not been involved in any crashes nor had she received any speeding citations. During the 16-day study period, she drove 195 miles, and made 36 trips. Overall, 45% of her driving activity is above the posted speed limit, and her mean deviation from the posted speed limit is 5 mph. Figure 83 and Figure 84 present this driver as a fairly modest driver with only one trip deviating above the posted speed limit by more than 15 mph. However, her compliance rate is only 50% because she exceeds the posted speed limit by more than 10 mph on half of her trips. A note of interest for this driver is that she did not complete any trips outside of the daylight hours. In contrast to the first and second case studies, this young driver did not exhibit any extreme speeding behavior during the course of the 16-day study period.

The final case study driver is the only driver out of the sample of 172 that had a compliance rate of 100%. Even this driver deviated from the posted speed limit by up to 10 mph on a few trips. Driver 6431 is a female, age 77, retired with a high school education. She lives alone and has a total household income between \$20,000 and \$30,000. During the study period, she drove 79 miles and completed 16 trips. This exposure level is low compared to others. She drives an older model large sedan. She has been involved in only one crash in her 62 years of driving. Figure 85 and Figure 86 show a very regular pattern of minimal speeding and minimal trip making. All trips occur between the hours of 10 AM and 1 PM during the weekdays. Only 12% of her driving exceeds the posted speed limit, and her mean deviation from the posted speed limit is 2 mph.

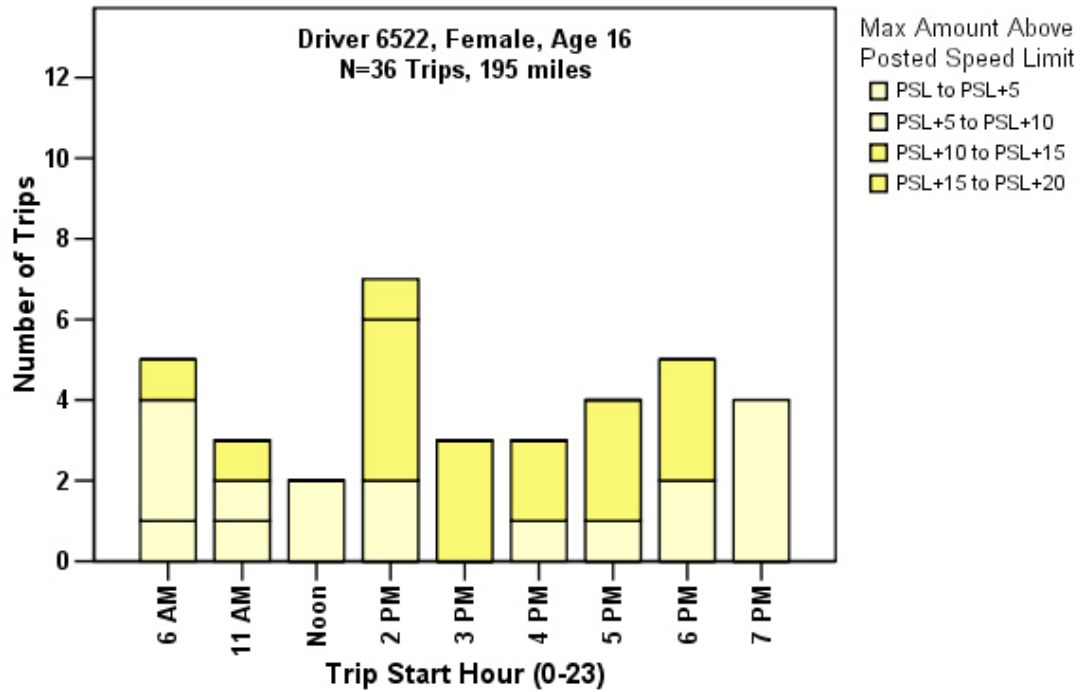


Figure 83 Trip Deviation Above the PSL by Trip Start Hour - Driver 6522

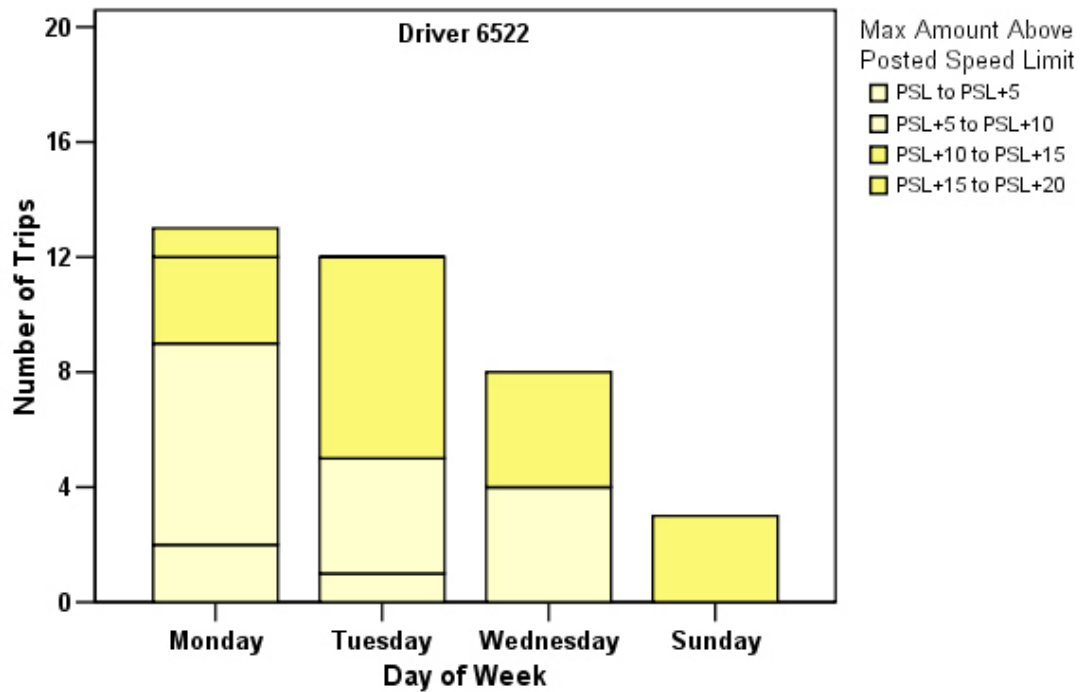


Figure 84 Trip Deviation Above the PSL by Day of Week - Driver 6522

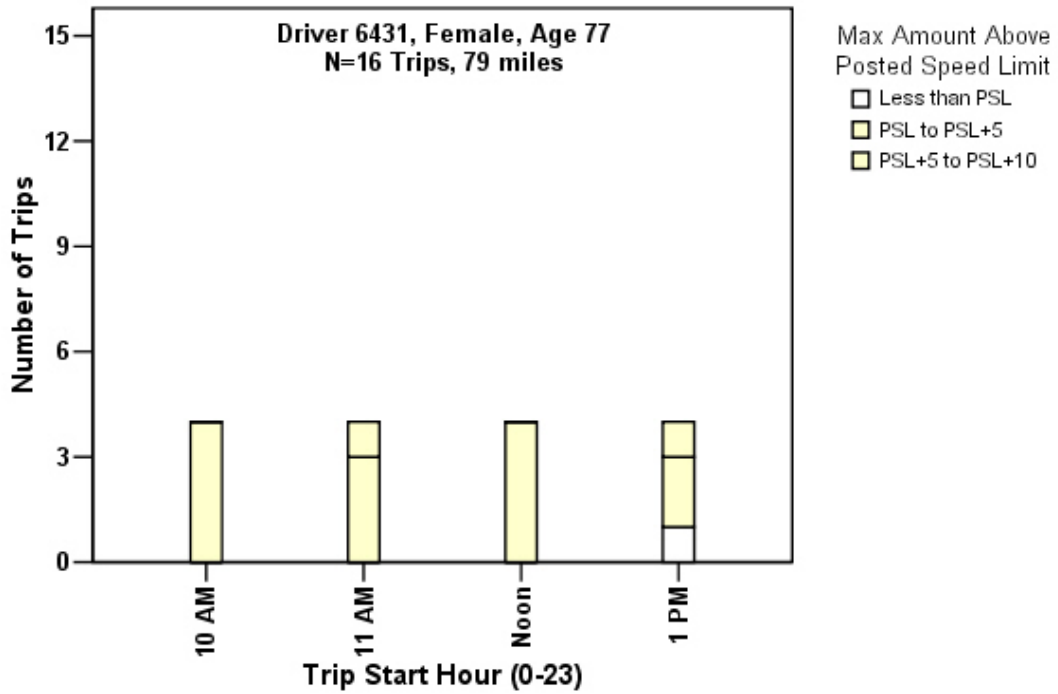


Figure 85 Trip Deviation Above the PSL by Trip Start Hour - Driver 6431

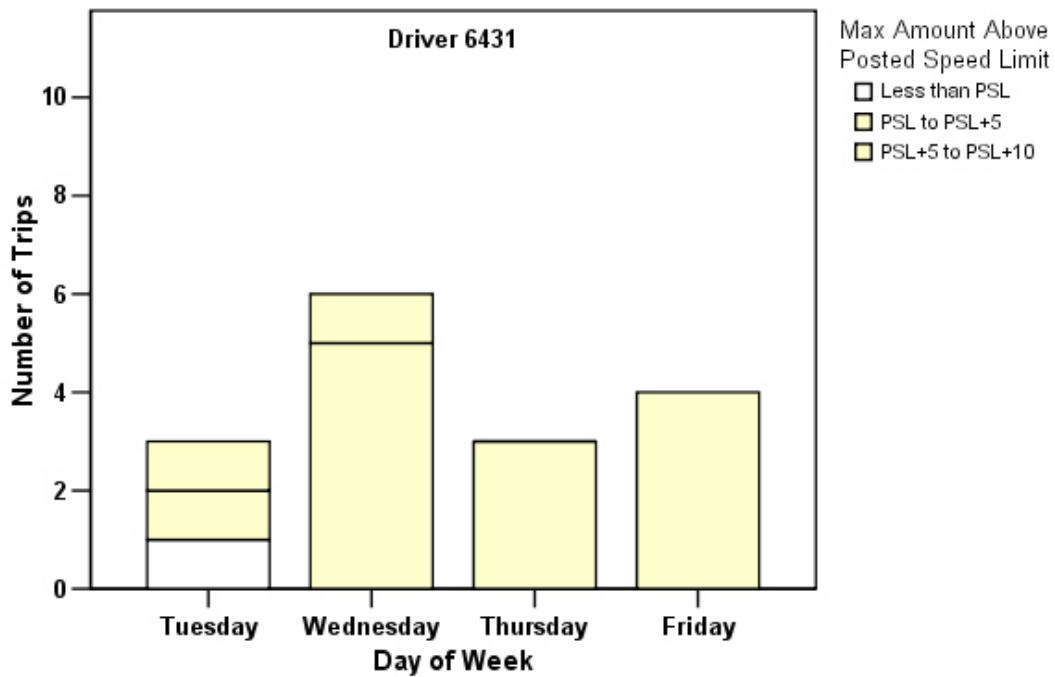


Figure 86 Trip Deviation Above the PSL by Day of Week - Driver 6431

As indicated in these six case studies, the patterns of speeding behavior are diverse, and no one metric explains the behavior fully. However, the ability to develop these driver profiles and quantify the amount, extent, and trend patterns could revolutionize the way in which we train young drivers. Using instrumented vehicles, the young driver could receive a weekly or monthly report card indicating all of the trips in which he/she failed to comply with posted speed limits, seat belt laws, etc. In fact, specific trip details, date, time and location could also be used to indicate the specific non-compliance activity. Further, the in-vehicle device could be programmed to give instantaneous feedback, either audible or visual, to the driver for speed or accelerations above predefined thresholds. This type of immediate and tangible feedback would allow the young driver to develop driving behaviors and skills based on appropriate responses to situations.

Exploratory Modeling Results

The purpose for developing speeding models within this research is to test the usefulness of instrumented vehicle data for modeling speeding behavior. Relationships were sought between speeding behavior and driving conditions or driver characteristics. Two hypotheses regarding speeding behavior and the corresponding model formulations were developed.

1. Driver speeding behavior is attributable to certain socio-demographic and exposure attributes
2. Driver speeding behavior can be associated with certain trip level attributes

An aggregate logistic regression model was used for the socio-demographic and exposure attributes, whereas, as disaggregate logistic regression model was used for the trip characteristics. The logistic regression model is a flexible tool for studying the relationship

between a set of variables and a categorical outcome. Using logistic regression, either a binary category of speeder/non-speeder, or various levels of speeders can be predicted.

Trip Level Models

This model of speeding behavior focused on trip-level speed. It was anticipated that a disaggregate driver speeding model would allow the capture of factors of individual trips that might lead to driver speeding behavior. The trip level model used logistic regression to predict the probability of speeding behavior in three categories:

- “Minimal” = exceeding the posted speed limit by 0 -10 mph
- “Moderate” = exceeding the posted speed limit by 10 – 20 mph
- “Extreme” = exceeding the posted speed limit by more than 20 mph

Trips were coded based on maximum positive deviation from the posted speed limit achieved during the trip. A minimum of 10 observations was required in the maximum positive deviation category to satisfy the coding criteria. This coding method is portrayed in Figure 60.

Initial models were developed using all trips regardless of time of day, day of week, functional class, etc. After many unsuccessful attempts, modeling efforts in this direction were abandoned. The logistic regression models did not provide satisfactory results at the aggregated trip level. Several attempts were made to reclassify data based on breaks identified through regression tree analysis, yet the results did not improve. These models lacked significance and contained too many variables.

A second attempt toward trip level modeling utilized a method developed by the Air Quality Laboratory at Georgia Institute of Technology for modeling high-emitting

vehicles. When modeling high-emitting vehicles, the cases must first be separated by facility type to reduce the variability due to differing roadway characteristics. Afterward, modelers use a standard case-control vehicle type for baseline comparisons across facilities and geographic areas. This technique lead to the separation of the trip set by facility type. The trips were split into smaller data sets based on roadway functional class and posted speed limit. Researchers tested a model using only trips on urban interstates with a posted speed limit of 55 mph. In total, 1,116 trips were identified for the modeling activity. This was the first modeling attempt that was successful in achieving significance (Table 19), albeit with relatively low R-Square values (Table 21).

Table 19 Urban Interstate (55 mph PSL) Trip Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	2187.702			
Final	1572.894	614.808	62	.000

Table 20 Urban Interstate (55 mph PSL) Trip Model Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	2196.440	2144	.211
Deviance	1566.877	2144	1.000

Table 21 Urban Interstate (55 mph PSL) Trip Model
Pseudo R-Square Values

Cox and Snell	.424
Nagelkerke	.492
McFadden	.280

Of the potential model variables listed in Appendix G, several variables were noted as significant for the Urban Interstate (55 mph PSL) Trip Model. The variables and their significance levels are noted in (Table 22). The list of variables includes: mileage exposure, age, number of jobs, vehicle age, trip start hour, percent of unconstrained observations, peak/off-peak, work status, occupation, gender, ethnicity, vehicle body type, marriage status, income, light condition, and urban/rural area type.

Table 22 Urban Interstate (55 mph PSL) Trip Model Significant Variables

Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	1572.894(a)	.000	0	.
TotalDistance	1616.175	43.282	2	.000
Age	1585.657	12.764	2	.002
NJobs	1602.410	29.516	2	.000
vehage	1584.176	11.283	2	.004
Trip_Start_Hour	1584.816	11.922	2	.003
Pct_Unconstrained	1798.315	225.422	2	.000
peakoffpeak	1600.967	28.074	2	.000
WorkStat	1614.032	41.138	2	.000
Occup	1605.636	32.743	8	.000
Gender	1582.946	10.053	2	.007
Ethnicity	1614.475	41.581	6	.000
vehicle_body_type	1601.681	28.787	6	.000
marriedsingle	1591.194	18.300	2	.000
Income	1697.035	124.141	14	.000
daylight	1598.423	25.530	6	.000
urbanrural	1599.940	27.047	2	.000

There were several significant variables that suggest that the work trip and the level of congestion of the interstate facilities were significant for identifying speeding levels (minimal, moderate, and extreme). The variables of interest were work percent of

unconstrained activity, work status, occupation, trip start hour, and income. Based on the previous case studies, a pattern of speeding appears to be associated with the morning commute. This trip type typically occurs on a fairly rigid schedule, and therefore drivers may be more willing to speed if possible in order to make it to work/school on time. Further, given the road network and sprawl in the Atlanta area, many commuters leave early in the morning to avoid the traffic. A second trip model was estimated with congestion considerations. The model data was filtered based on the ‘Percent of Unconstrained’ activity from the valid observations. Trips undertaken during ‘constrained’ conditions were removed from the dataset leaving only trips with more than 90% of the observations unconstrained. This effort reduced the total number of potential trips in the valid set to 497. The resulting trip model had a reduced set of model variables while maintaining significance (Table 23) and good model fit (Table 25).

Table 23 Unconstrained Urban Interstate (55 mph PSL) Trip Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	640.970			
Final	473.045	167.925	62	.000

Table 24 Unconstrained Urban Interstate (55 mph PSL) Trip Model Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	422.822	404	.250
Deviance	381.376	404	.785

Table 25 Unconstrained Urban Interstate (55 mph PSL) Trip Model
Pseudo R-Square Values

Cox and Snell	.287
Nagelkerke	.358
McFadden	.210

Given the positive results of the unconstrained urban interstate model based on limited data (<500 trips), there is great expectation for the usefulness of speed/speeder prediction models developed from larger data sets. The steps taken during model development suggest that moving from aggregate trip based models to models that represent a particular road type and posted speed, or possibly other road characteristics, will increase prediction capabilities. Initial recommendations include separating facilities between freeways, arterials, collector, and local streets. It is anticipated that these groups will need to be further divided by posted speed limit, which is often related to design speed.

Table 26 Unconstrained Urban Interstate (55 mph PSL) Trip Model
Significant Variables

Effect	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	473.045(a)	.000	0	.
TotalDistance	478.368	5.323	2	.070
Age	481.128	8.083	2	.018
peakoffpeak	496.793	23.748	2	.000
WorkStat	481.846	8.801	2	.012
Gender	482.161	9.115	2	.010
marriedsingle	482.383	9.338	2	.009
Income	505.818	32.773	14	.003
daylight	490.701	17.656	6	.007
urbanrural	481.608	8.563	2	.014

Separating the trips based on the constrained operations seemed to provide another level of significance. While the definition of constrained operation and data to support the assumption of constrained operation was somewhat deficient, it is clear that this information is critical to future speeding behavior studies. The ability to accurately discern whether the drivers' speed is chosen or a derivative of car-following behavior would provide yet another level of certainty in the categorization of a speeder/non-speeder, or normal, moderate, or extreme speeder. Over time, the equipment to allow widespread GPS instrumentation has dropped in price. Eventually, reasonably priced radar devices will allow widespread deployment of headway measurement in future instrumented vehicles.

Finally, significant independent variables in the final unconstrained interstate trip model (employment and exposure) indicate that trip purpose may be useful for predicting driver speed. Initially researchers hypothesized that the morning peak period would not be critical for predicting speed based on the traffic volume. However, as shown in the case studies, there is a whole different type of speeder that participates in extreme speeding primarily in the morning commute. The use of simultaneous panel-type travel diary studies with instrumented vehicle studies will provide trip purpose information for numerous types of research and modeling efforts. In the Commute Atlanta program, the combination of these two types of studies is proving highly useful for determining patterns of non-response and under-reporting of certain types of trips (Ogle and Guensler, 2005). For instance, households with few or no trips are less likely to complete the interview process, as well as are households that make really large numbers of trips (>17 to more than 30 trips per day per household).

Driver Characteristics Model

The second type of model was developed to study the effects of socio-demographic and exposure related elements on driver speeding behavior. Again, logistic regression was used to develop a model to predict probability of speed compliance in three categories:

- “Minimal” = higher than 80th Percentile Compliance Score
- “Moderate” = between 80th and 20th Percentiles of Compliance
- “Extreme” = less than 20th Percentile Compliance Score

Researchers calculated the compliance score using the ratio of speed compliant trips (not exceeding the posted speed limit plus 10 mph) to unconstrained trips. This is a measure of the persons desire to exceed the posted speed limit when the opportunity is available. Drivers with very low compliance scores tend to exceed the posted speed limit by more than 10 mph on a nearly constant basis. Drivers with a high compliance score rarely tend to exceed the posted speed limit by more than 10 mph. The results of the logistic regression model attempts were poor. Logistic regression did not produce significant results for the aggregate driver file for potentially several reasons. One reason is due to the small number of drivers (172) divided into three long-term trend speeding categories. Another is the extreme variability between drivers as well as within drivers. With a minimum total of 16 trips for one driver during the 16-day period, the sample sizes were too small to achieve statistical significance. Finally, the aggregation of all trips over all facilities may give a misleading trend if a specific driver only tends to speed on one class of roadway. Further analysis of these potential problems on a much larger dataset may result in better outcomes.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this dissertation research was to develop a framework and methods for quantifying and analyzing individual driver behavior using instrumented vehicles. The goals of the research were threefold:

- Develop processing methods and observational coding systems for quantifying driver speeding using instrumented vehicle data;
- Develop a framework for analyzing aggregate and individual driver speeding behavior; and
- Explore the potential application of behavioral safety concepts to transportation safety problems.

For this research, 172 instrumented vehicles from the Commute Atlanta program were utilized to collect individual driver speeding behavior. Continuous monitoring capabilities allowed the capture of speed and location for every second of vehicle operation. Driver speeds were then matched to road networks and subsequently to posted speed limits using a geographic information system. Differences between the drivers speed and the posted speed were calculated for each second of operation. Several processes were developed to assess the accuracy and the completeness of the data prior to analysis. Finally, metrics and analysis frameworks were tested for their potential usefulness in future behavioral risk analysis.

The results of the research were both positive and staggering at the same time. Speeding behavior is widespread in Atlanta. On average, nearly 40% of all driving activity by the sample population was above the posted speed limit, and approximately 12% of driving activity occurs more than 10 mph above the posted speed limit. Further, the distribution of mean positive deviation above the posted speed limit is centered about the legislated enforcement threshold (10 mph over PSL), this is also commonly the difference between the posted speed and the design speed.

The amount and extent of speeding behavior was highest for young drivers. Trends indicate that speeding behavior decreases in amount and extent as age increases. However, as the case studies reveal, random occurrences of extreme deviations from the posted speed limit exist at the individual driver level in most age groups. The patterns of extreme speed vary widely, but in general terms, early morning commuting trips as well as weekend trips are more likely candidates for display of this type of behavior.

Although the young driver group showed the highest mean levels of speeding, all young drivers do not exhibit extreme speeding behavior. This is important to note, because current insurance rate structures for young drivers do not account for these differences. Two young driver case studies highlighted extreme deviations from posted speed limits – in excess of 40 mph above the posted speed limit. This type of speeding behavior should be identified and modified.

Three speeding behavior metrics were developed for this research. Each metric describes a different parameter of driver speeding behavior:

- Amount – the fraction of observations above the posted speed limit

- Extent – the distribution of mean positive deviation above the posted speed limit
- Long-term trend – the ratio of compliant to non-compliant trips

The total account of driver speeding behavior is best achieved by using all 3 metrics, as well as an array of charts and statistics. Overall, the research demonstrated that driver speeding behavior can be quantified using instrumented vehicles. Further, while the results of the logistic regression modeling efforts were not perfect, they did show promise for future speed prediction models given larger sample sizes and more homogeneous datasets.

To fully answer the questions remaining from previous research, a much larger instrumented vehicle sample is required. As well, additional technologies are needed to capture positive driver identification (with minimal intrusion), weather conditions, and other behavioral components such as car-following headway, braking, safety belt use, and cell-phone use. Recommendations for future research include other potential metrics for driver behavior including acceleration and deceleration activity, and speed oscillation.

Contributions to Transportation Safety Analysis

This research contributes in a number of ways to the advancement of transportation safety analysis. First, it steps outside the bounds of traditional automotive and roadway engineering failure analysis to explore the use of behavioral safety techniques for analyzing driver behavior. Second, this analysis methodology changes the focus from counting crashes to quantifying precursor behaviors. The ability to quantify precursor behaviors would eliminate the need to wait until a crash has occurred to intervene and modify problem behavior – such as those extreme speed deviations observed in the young case study drivers. Early detection and intervention techniques for problem behavior have been

highly effective (nearly full elimination of accidents) within industrial settings. Third, this research relies on instrumented vehicle technologies to collect accurate detailed data on driver speed behavior and exposure. This type and magnitude of data collection are unprecedented. Fourth, the study area for the data collection is primarily urban, whereas most previous research on speeding behavior focused on rural areas. Fifth, this research resulted in the development of an analytical framework and data collection techniques that can be used to study other driver behaviors such as seat belt usage, car following, and turn signal usage. These represent other examples of behavior noted in the literature review as contributing to a large number of crashes, injuries and fatalities. Finally, this research allows the quantification of speeding behavior at the individual level based on complete speed and exposure information.

Future Research Directions

The next step is to assemble driver speeding behavior profiles with pre-crash speeds to discern whether drivers that speed regularly or extremely are at a greater risk of crashing. The collection of pre-crash speed data can be undertaken using standard instrumented vehicle data or by using event data recorder data from in-vehicle airbag modules. Regardless of the data source, the ultimate answer to this question will require far more driver behavior profiles and crash observations than what a 500 vehicle study can provide. A national effort will be required.

Figure 87, Figure 89, and Figure 88 portray an actual crash event that occurred during the study period. Figure 87 shows the location of the crash. The participant was approaching a signal and was rear-ended at the intersection. As noted in Figure 88, as the

driver approached the intersection the vehicle speed was approximately 5 mph above the posted speed limit. The driver gradually slows the vehicle to stop at the signal while the vehicle in the rear fails to stop. In this case, the positive speed deviation did not appear to contribute to the crash. However, the speed of the impacting vehicle may have contributed. Continuous recording of driver speeding behavior allows analysts to go back in time as well as ahead in time and find trips on the same road at the same time of day in a case control manner. Figure 89 shows a trip at the exact same location made three days later within two minutes of the actual crash time. An identical pattern of speeding exists for this situation – however, the signal changed and the driver was not required to come to a full stop. This example shows the potential for risk analysis, without the need for sometimes proprietary event data recorder data.

Additional research can take many forms:

- Test the ability to modify driver speeding behavior by providing feedback and using behavioral safety intervention techniques
- Further the development of driver speeding models with additional data obtained during the baseline
- Explore additional independent variables such as trip purpose and attitudinal scores for use in models

The possibilities for studying driver speeding behavior and other driver behaviors are seemingly limitless.

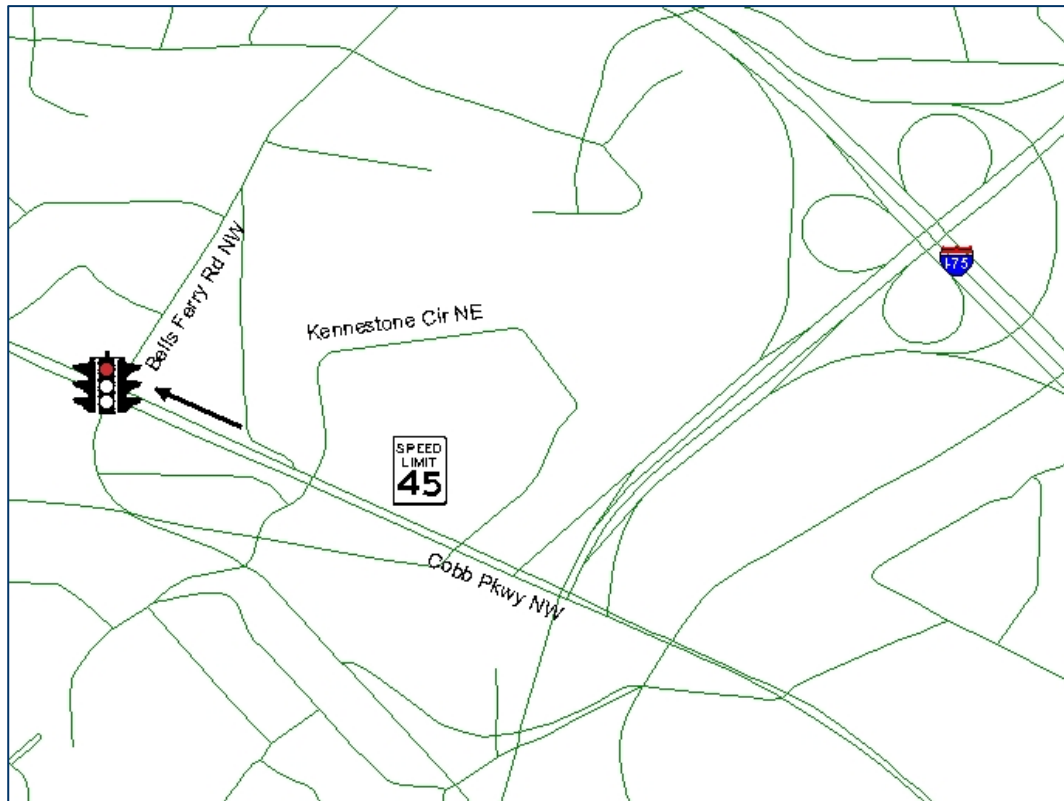


Figure 87 Crash Case Study Location

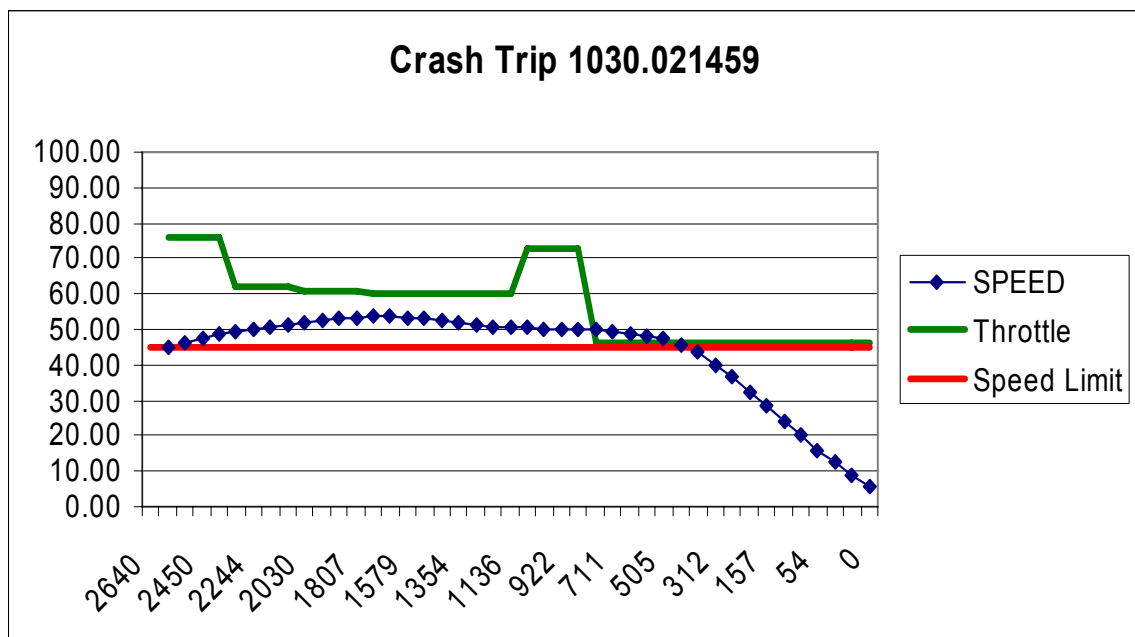


Figure 88 Pre-Crash Speed and Throttle Position

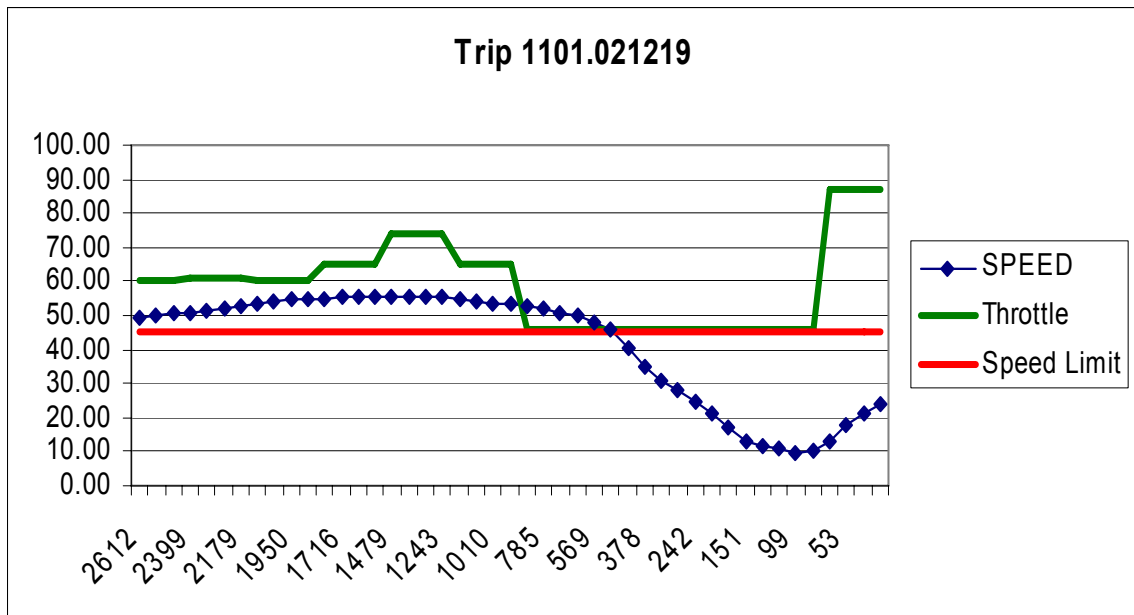


Figure 89 Case-control Speed and Throttle Position

APPENDIX A

Behavioral Safety Overview Paper

Behavioral Safety Overview with Special Focus on Applications in Transportation

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Abstract

The development of operant conditioning by B.F. Skinner led to the practice of behavioral safety techniques in reversing unsafe behavior. This paper provides an overview of the history and components of behavioral safety programs for effective safety performance in the workplace. Component features including definition of critical behaviors, methodologies and observation techniques, intervention through antecedents and consequences, and evaluation of program effectiveness. A focused set of literature regarding behavioral safety in transportation is also included along with potential areas for future research.

What is Behavioral Safety?

Behavioral safety is, in essence, the application of behavioral analysis techniques to produce changes in behavior in the workplace. The goal is the reduction of unsafe performances by workers. Behavioral safety techniques have been applied in numerous settings (i.e., mining, transportation, and bakeries), and have been shown to be highly effective in the reduction of unsafe behavior. Workplaces that have experienced high accident rates over extended periods have applied behavioral safety techniques resulting in accident rate reductions of nearly 70% in the first few years after implementation (Krause, 1997). Increases in the safe performance of work activities result in reduced injuries and illnesses, with further reductions in costs associated with these injuries. Effectively implemented programs often pay for themselves (Krause, 1997).

The components of behavioral safety programs vary slightly depending on the circumstances of the implementation setting. Successful implementations create systematic processes that weave themselves into the daily operations of the company as standard operating procedures. This generalization helps to support the overall safety management operation of the company.

The identification of behaviors that reduce the risk of injury and accidents allows for opportunities to observe and record the frequency of these behaviors over time. Workers can be empowered to take control of the safety of the company, and more personally, their workspace. Continual feedback and positive reinforcement of appropriate behaviors increases and maintains those behaviors, thus creating a safer workplace.

Introduction to Behavioral Analysis

The work of B.F. Skinner set the stage for behavioral safety analysis with the development of his psychological theories of learning (Bird and Schlesinger, 1970). His theory of operant conditioning is quite simple in nature – behavior is influenced by its' consequences (Pierce and Epling, 1999). By controlling the consequences of behavior on a schedule, you can begin to “shape” or modify behavior.

Baer et al. describe the application of behavior analysis as “the process of applying sometimes tentative principles of behavior to the improvement of specific behaviors, and simultaneously evaluating whether or not any changes noted are indeed attributable to the process of application – and if so, to what parts of the process” (Baer et al., 1968, pg. 91). Baer et al. (1968) continue in their review of applied behavior analysis to define specifically the terms ‘applied’, ‘behavior’, ‘analysis’, and others. A brief summary of these definitions follows:

- Applied – refers not to the application of behavioral analytic techniques in general, but the application of these techniques for socially important behaviors relating directly to a particular subject. For example, socially important behavior in retardates will not include visual signal detection; however, this behavior is very important for radar-scope operators.
- Behavior – refers to the precise measurement of what a person does not what a person says he can do. Since this measurement cannot always be possible by instrumented-recording capabilities, behavioral analysis programs often employ human observers. Thus, this begs the question, ‘If behavior is noted as changed – was it that of the recorder or that of the observed?’ The use of multiple observers can eliminate some of these questions.
- Analytic – refers to the demonstration of events reliably followed by particular behaviors. Analysis of behavior is achieved when the behavior comes under control of the experimenter. Two frequently used designs for showing control are the reversal technique with the experimental variable, and the multiple baseline technique. The goal for using these techniques is to show reliability in the behavioral pattern achieved through intervention procedures. Variable reinforcement patterns further establish reliability of control.
- Technological – refers to the identification and description of the complete set of environmental elements and contingencies under which behavior are under control. The main idea is to record enough information so that the demonstration

of behavioral control could be repeated.

- Effective – refers to the practical significance of the change in behavior. Multiple repetitions showing control over behavior may produce statistically significant changes in behavior, however, the importance of significance is purely practical. A repetitious reduction in driver speeding performance of one mile per hour is not practically significant if the driver is a problematic speeder...exceeding the speed limit by 25-30 miles per hour consistently.
- Generality – refers to the long-term continuation of a particular behavior, and the overlap of that important behavior to other similar situations.

Origins of Behavioral Safety

Dr. Judith Komaki pioneered the research in behavioral approaches to safety in the late 1970's. In 1978, she and colleagues Kenneth Barwick and Lawrence Scott, all of the Georgia Institute of Technology Engineering Experiment Station, published a paper entitled "A Behavioral Approach to Occupational Safety: Pinpointing and Reinforcing Safe Performance in a Food Manufacturing Plant" in the Journal of Applied Psychology. The paper describes a behavior analysis approach used to improve safety performance at a food manufacturing plant. The study involved identifying desired safety practices and construction of observational codes suitable for observing workers performance over a 25 week period. The intervention consisted of an explanation and visualization of desired behavior, as well as low cost reinforcement for correct behavior in the form of feedback. Employees in two departments were involved in the study and their safe behavior performance improved from 70% and 78% to 96% and 99%, respectively, after the introduction of the program. However, during the reversal phase, the safety levels dropped back to 71% and 72%. Researchers concluded that the feedback was necessary and effective in improving safety performance. The employees reacted favorably to the program, and the company was later able to continue decreased accidents by defining and positively reinforcing safe behaviors.

This study led to numerous others by Komaki in the late 70's and early 80's on the academic side. In the early 80's, Thomas Krause and colleagues were starting a similar movement defining an implementation for industry on the private sector side called "behavior-based safety process". It was during this time, that many companies adopted portions of the program under the same or similar names leading to several other articles on what is and is not behavior-based research. In the early 1990's, Dr. E. Scott Geller of Virginia Tech entered again on the academic side using behavioral safety techniques for driver safety improvements.

Applications of Behavioral Safety in Transportation Engineering

In 2000, there were approximately 212 million licensed drivers in the United States. Motor vehicle travel remains the primary means of transportation in the United States providing mobility unparalleled to other nations. However, despite vast improvements in safety records over the last several decades, motor vehicle crashes still account for 90% of the nations transportation-related fatalities, and 99% of the transportation-related injuries. Motor vehicle crashes continue to be the leading cause of death for persons ages 4 to 33. (National Highway Traffic Safety Administration, 2000)

The year 2000 recorded a historically low fatality rate of 1.5 fatalities per 100 million vehicle miles traveled. This was down from 1.6 over the period 1997-1999. In comparison, the 1990 rate was 2.1 fatalities per 100 million vehicle miles traveled. Regardless of the dropping fatality rates, the number of actual fatalities rose to 41,821. This equates to approximately 115 losses of human life per day or the loss of one life every 13 minutes to motor vehicle crashes. Nationwide, total daily losses are comparable to one fatal plane crash – although these single losses do not make the national news like aircraft crashes. One might ask, 'Is the individual loss of life any less important?' (National Highway Traffic Safety Administration, 2000)

The fatalities are only a portion of the problem. Police reported motor vehicle crashes occur once every 5 seconds, totaling 6.3 million crashes per year. Adding in property-damage-only crashes brings this number up to 8-10 million crashes per year. Injuries resulting from motor vehicle crashes are in excess of 3 million (3,189,000 in 2000). Economic losses from motor

vehicle crashes are greater than \$2 billion per year. (National Highway Traffic Safety Administration, 2000)

The concept of transportation safety implies the avoidance of accidents. Over the years, many transportation safety programs have focused evaluations on the study and measurement of accidents and severity. By examining the accidents, engineers seek to find causal elements of crashes and strive to change roadway and vehicle design to account for additional safety margins. Petroski eloquently defends this type of analysis and re-engineering in his 1985 book, *To Engineer is Human...* by stating, “I believe that the concept of failure – mechanical and structural failure in the context of this discussion – is central to understanding engineering, for engineering design has its first and foremost objective the obviation of failure. Thus the colossal disasters that do occur are ultimately failures of design, but the lessons learned from those disasters can do more to advance engineering knowledge than all the successful machines and structures in the world. Indeed, failures appear to be inevitable in the wake of prolonged success, which encourages lower margins of safety. Failures in turn lead to greater safety margins and, hence, new periods of success. To understand what engineering is and what engineers do is to understand how failures can happen and how they contribute more than successes to advance safety” (Petroski, 1985, p. xii). Safety programs that have been enacted have not been as successful as they could or should be due to the infrequent and unpredictable nature of accidents, thus making benefits difficult to observe (Komaki, 1978).

Engineers in the transportation field are fraught with problems related to this type of analysis methodology. For starters, engineers have done little to study the human behavioral components of crashes (i.e., speeding, following too closely, inattention, disregard of safety devices, driving under the influence, etc.). Instead of dealing with these behaviors, engineers have even begun trying to engineer around them. For example, new Intelligent Cruise Control systems maintain appropriate following distances for the driver by speeding up and slowing down automatically based on forward seeking radar technologies. ABS brakes are another system that was designed to allow the driver to remain in control of the vehicle direction in a locked brake situation – allowing better handling in extreme maneuvers from unsafe behaviors such as following too closely. Cognitive and engineering psychologists have contributed greatly to the fields of signage, markings, and cockpit design, but little attention has been given

to contributing factors related to what the driver is actually doing in the vehicle. Due to inadequate accident reporting forms and investigative techniques and other data sources, little information is gleaned from these accidents to stem recurrences of the behavioral component. Further, there is a common opinion among engineers that behaviors cannot be changed, thus they tend to be ignored.

It is no wonder that crashes (transportation system failures) receive so much attention. They are traumatic events that cause pain, suffering, loss of life and property, but more importantly they are easy to identify. Unfortunately, focus on the accident as the primary item of interest impedes the application of more useful information contained in the magnitudes of unsafe behavior performance that precedes the accident (Krause, 1984). Behavioral safety programs seek to identify behaviors contributing to accidents and define contingencies to eliminate and replace those unsafe behaviors.

The actual determination of unsafe behaviors that will lead to accidents is a very difficult task. The likelihood that a single unsafe behavior will cause an accident is left to mere chance. It cannot be disputed, however, that increases in the frequency of unsafe behavior will lead to increases in accidents. The opposite is true too – decreases in unsafe behavior should also decrease accidents (Krause, 1984). In this respect, behavioral safety programs have potential to produce successful driver safety programs.

Behavioral Safety in Transportation: A Case Study

“In 30 minutes, or it’s free!” is a familiar slogan for a national pizza delivery chain. The consequences of these promotions on driver behavior in these companies is outrageous. Driving fast and avoiding time-consuming behaviors, such as applying seat-belts and turn signals, are only a couple of unsafe behaviors reinforced in such a system. Ludwig and Geller (1991) devised a behavioral safety program for one such pizza delivery chain in Virginia. Researchers observed seat belt use during regular delivery arrivals and departures (approximately 12 per hour). Three stores were used in the experiment, with one remaining non-treatment control group throughout. At the start of the experiment, there were no safety belt guidelines in the employee handbook section on safe driving, but there was a secondary

seat-belt law in place in Virginia at the time. The secondary safety belt law allows officers to ticket the safety belt offense as a secondary offense to another traffic violation.

Researchers used a multiple baseline treatment phase followed by observations in a reversal phase. The drivers of the two treatment stores received safety belt awareness training including threat of dismissal for refusing to wear the seatbelt. Driver seat belt and turn signal use was observed at intersections adjacent to the stores. On the day of the training, seatbelt usage on arrival was 42% versus 100% on departure after the drivers had signed seatbelt promise cards. The Blacksburg treatment store had an average baseline usage rate of 41%, 68% during intervention, and 69% in reversal (see Figure 1). At the Christianburg treatment store average baseline belt use was 14%, with 69% in the intervention stage, followed by 42% during reversal. The belt use at the control store remained steady at approximately 45% during the baseline, intervention, and reversal periods at the other two stores. When age was factored in, the under 25 group showed significant increases in belt use over their older counterparts (maybe you can't teach an old dog new tricks). As well, individual differences were hidden in the average values reported. Most drivers responded to intervention, however, few showed no effect.

While this study by no means shows the best performance of behavioral safety techniques, it is a good example of the potential benefits and problems of behavioral safety programs in transportation. The researchers used the multiple baseline method as shown in Figure 1. All participating stores went under observation at the same time. The Blacksburg store began intervention in mid-November, and the Christianburg store began intervention in early December. The intervention at the Blacksburg store lasted approximately a month, while the Christianburg intervention was only about a week in length. The follow-up portion shows the reversal stage observations. Note that the store with the longer intervention period maintains a higher average during the follow-up period. Also note the variation in measurements among all stores. This variation is dependent on individual variation of the involved participants.

Several issues arose upon completion of the analysis. While turn signals were not targeted by the study, a statistically significant increase was noted along side that of increased safety belt use. This suggests that response generalization occurred. As second item of interest was the fact that different definitions of risk developed differing patterns of responsiveness to the

intervention programs. Further information is needed for the development of relationships between indicators of risk and driving patterns, as well as indicators of risk and response to different types of interventions. Finally, the author's suggested longer-term demonstration projects and more expensive intervention techniques for unaffected participants (Ludwig and Geller, 1991).

Four Major Components of Behavioral Safety Programs

Following closely the elements of behavioral analysis defined according to Baer earlier and the techniques outlined in the illustrative case study, most behavioral safety programs have approximately four major components. In any program, the first task is to define the problem. In behavioral safety, this component involves the definition of critical behaviors for safe performance. The definition of these behaviors relies heavily on previous accident reports as well as through direct observations. .

Direct observations are usually critical to the development of observation codes and taxonomy for recording behavior. Once the target behaviors have been coded, those behaviors must be observed in a pre-intervention baseline setting. Collecting baseline information allows researchers the ability to determine the magnitude of change of the intervention strategies.

The third phase is typically the one with the most variation from program to program.—the intervention stage. Intervention can include training and/or other antecedent operating procedure announcements, consequences in the form of reinforcement (positive or negative), and finally some form of feedback system. The latter of these is the most commonly used technique across all programs. The final and most important stage of the program is to test the impact through observations, recording and evaluation (Komaki, 1978). Each of these phases is described in detail below with supporting information from a thorough review of research.

Define Target (critical) Behaviors

As behavioral safety has evolved over the last couple of decades, so too has the terminology. In the beginning, behavior associated with accident situations became known as unsafe behavior. Therefore, the word “unsafe” was perceived as a negative term. Workers opposed programs implemented to find fault. In an effort to place these programs in a more favorable light, the term “at-risk behavior” was coined (Krause, 1997). At-risk behavior is behavior that has been defined as critical to safe performance, such as putting on goggles before beginning an experiment in a chemical laboratory.

Unsafe behaviors can be roughly estimated to show that millions of unsafe behaviors may occur before an accident occurs. Given a rate of 3.21 lost-time accidents per 100 employees, with 2000 hours worked per employee per year, and 2 behaviors performed per minute, in one year, 24,000,000 behaviors are performed. If 10% of behaviors are performed in an unsafe manner, an average of 747,663 unsafe behaviors would be performed for each accident (Krause, 1984). It is difficult, however, to determine which behaviors are critical to incidents. Determination requires direct observations, supervisory and worker input, task analysis, and a review of accident reports. Following are a few methods for the identification of critical behaviors.

Pinpointing safe behaviors is the first step to developing successful behavioral safety programs. In the groundbreaking research by Komaki et al. (1978), accident reports and supervisory input were used to begin the development of observational codes. Observational codes were developed for each of three departments in a food manufacturing plant. Vague phrases were not used; instead, each behavior was clearly defined. For example, in the makeup department one behavior was coded as ‘When lifting or lowering dough trough, hand holds and at no time loses contact with dump chain.’ Further, items with obvious results (i.e., boxes on the floor) were used over actions (i.e., dropping boxes). By defining behaviors/outcomes exactly, inter-observer reliability is can reach high levels.

Definitions of behavior should be written such that two observers can read the definition, observe the same behavior, and independently record the same observation (Fitch et al., 1976).

Periodic sampling of inter-observer reliability can uncover any biases injected into the process by the observer. Variability in the observations can also signal the need for changes or additions to the observational codes (Komaki et al., 1986).

Altman (1970) provides a slightly different view of error analysis. He believes that there are error opportunities and error possibilities. Opportunity for error occurs with each task and activity to be performed. Error possibility refers to the possible errors related to each task. By observing and recording errors, one can pinpoint those that are most prone to critical error. These critical errors are most suitable for selective observation. Altman suggests developing a matrix of detectability, revocability, and consequences to pinpoint critical behaviors (see Figure 2). Those errors occurring at the bottom left of the matrix are both detectable and revocable causing the least amount of consequence. Those errors occurring at the top right of the matrix are undetectable and irrevocable. Those in between these two areas are of greatest concern.

Altman (1970) also defined classes of error for different behavioral levels. Behavioral levels from problem solving to sensing and detecting are included in Table 1. For each behavior, omission and commission errors are denoted. From this table, conditional probabilities can be defined and evaluated.

Observe Behavior in Pre-Intervention Baseline

Study Design and Methodology

Before delving into the observation of behavior in the pre-intervention baseline, it seems necessary to define the baseline and research methodologies. As mentioned earlier, two frequently used designs for showing control are the reversal technique with the experimental variable, and the multiple baseline technique. The goal for using these techniques is to show reliability in the behavioral pattern achieved through intervention procedures. Reversal techniques examine one behavior in repeated experimental conditions (also referred to as A-B-A-B reversal). Multiple baseline techniques examine many behaviors, sometimes with some in one experimental condition while others are in a different experimental condition. Schedules of reinforcement (multiple, mixed, and concurrent) defined in the experimental analysis of

behavior research have also been applied in behavioral safety programs. Multiple texts have codified various experimental designs; however, it is still considered best practice to design an experimental methodology to answer a question, rather than fit the question to a pre-determined design. (Baer et al., 1987)

The baseline is commonly referred to as the A-phase (Pierce and Epling, 1999). This phase occurs prior to any introduction of intervention techniques. Observers measure safe and unsafe performances in repeated sessions. This allows a per-intervention performance trend line to be established. After intervention begins, more measurements are made and changes are noted in the safe and unsafe performances. In reversal, return to baseline establishes that the treatment was responsible for the behavioral change. In many situations, return to baseline is not possible. For those, the multiple baseline technique is generally favored.

One very important threat to validity is an effect called reactive measurement (Pierce and Epling, 1999). This effect occurs due to the fact that the behavior in question is being measured. In this situation, the act of measurement changes the behavior being measured rather than or in addition to intervention techniques. Thus, many methods use covert observation techniques.

Observation Quality and Consistency

There are two main keys to obtaining quality and consistent data for measurement of the effectiveness of behavioral safety programs: 1) the detail of the behavioral codes and forms; and 2) retaining highly trained observers (Krause, 1995). Contrary to initial thoughts, the most advantageous observer is not the supervisor, but the wage-roll employee. These personnel tend to have the most knowledge about the job being performed, are interested in safety, have credibility with their peers, and should be able to communicate well with their peers. Supervisors should only become observers after much training, and even still may be perceived negatively as 'safety cops'. External observers can also be used to provide objective observations, but require extreme amounts of training prior to becoming effective on the job.

Using the critical behavior inventory and observation codes, observers measure and record the number of safe behaviors performed. It is unusual that all occurrences of the behavior can be

evaluated; therefore, sampling schemes must be developed for pre-intervention, intervention, and follow-up phases. Sampling can occur over departments, shifts, seasons, and by individual. In any sampling plan, frequency of observation is key. Feedback in intervention relies heavily on observation measurements of safe behavior. The premise of behavioral safety programs is that feedback drives behavior change (Krause, 1997).

Obstacles to Observation

Krause (1997) defines a number of obstacles to high quality observation, they are:

- Resistance from wage-roll employees,
- Resistance from unions,
- Resistance from supervisors,
- Over-familiarity with the work (overlook hazards),
- Unfamiliarity with the work (don't know where hazards lie),
- Unfamiliarity with the data sheet,
- Behavior that happens quickly (unsure of proper behavior performance), and
- Small but important things (little things become big things in a crisis).

Intervene to Change Behavior

The third level in the behavioral safety program and that with the most flexibility is the intervention stage. Interventions can come in the form of antecedents or consequences, or both. Antecedents are those things that come before behavior and consequences are those that follow behavior. Krause (1997) identified the 'ABC Analysis' or antecedent-behavior-consequence analysis. A simple example is common in everyday situations: a phone rings (antecedent), a person answers it (behavior) to hear someone talk back to them (consequence). The most salient of the antecedent and consequence at first glance appears to be the phone ringing, however, it is the person on the other end of the telephone line that actually provides the more powerful predictor of behavior. The ultimate goal of ABC analysis is to determine

what combination of antecedents and consequences changes behavior. Krause (1997) also give the following principles related to antecedents and consequences, “both antecedents and consequences influence behavior, but they do so very differently, consequences influence behavior powerfully and directly, and antecedents influence behavior indirectly, primarily serving to predict consequences.” Numerous studies have been published regarding the effects of all of these. The following excerpts from research represent a small sampling of the findings.

Antecedents

Antecedents can come in many shapes and sizes. They are also referred to as activators and can include activities such as behavioral goal setting, training on proper behavior and topography of behavior, reminder signs and posters, voluntary commitments, and changes in policies and standard operating procedures.

Goal-setting

Komaki et al. (1978) and Fellner and Sulzer-Azaroff (1985) both concluded that goal setting is important in the improvement of safe performance in the workplace. Geller (1998) recommends setting SMART goals. The acronym stands for specific, motivational, achievable, recordable and trackable goals. The motivation comes into play by defining what will happen when the goal is achieved (consequences). Tracking progress can also allow intermittent steps to also be rewarded. By achieving intermittent step-goals, the progress is reinforced and behaviors are maintained.

Ludwig and Geller (1997) compared the impact of assigning versus participatory goal setting while studying the effects of targeted and non-targeted behaviors. Three behaviors were unobtrusively observed in two pizza delivery stores and included: intersection stopping, turn signal use, and safety belt use. The targeted behavior was the completion of full stops at intersections. The researchers hypothesized that turn signal use and safety belt use would increase with intersection stopping in groups participating in the goal-setting process, but not with groups having assigned goals. Baseline stopping at both stores was 55% in the initial

period. During an open discussion, one of two participating stores set a storewide goal 75% complete stops. In the other store, a 75% complete stop goal was mandated.

Goal setting and feedback increased safe intersection stopping in both groups. This is consistent with earlier findings on the effectiveness of goal-setting. No significance was noted between participative versus assigned goal-setting groups. Generalization of behavior across two related driving behaviors was also tested. The non-targeted turn signal use and safety belt use behaviors increased in relation to the group that participated in goal-setting, and the opposite occurred in the assigned-goal group. Non-targeted behaviors actually sustained decreases over the study period in that group. Analysis shows that beneficial side effects of participative goal-setting include generalization of increased safety behaviors on related behavior class elements. Researchers suggested further testing of other behaviors in this class to include speed and following distance.

Other Antecedents

Komaki et al. (1982) devised an experiment to test the criticism of emphasizing consequences over antecedents. Typically behavioral safety programs include both antecedents and consequences introduced simultaneously making it difficult to distinguish the effect of one over another. Although previous studies tested the role of antecedents, the saliency of the antecedent was minimal and reversal was almost immediate because the antecedent training occurred only once with no follow-up. This experiment utilized constant management involvement with multiple baseline techniques in a meat processing plant. The antecedent condition was introduced first with safety rules explained in a slide show, display of rules in each department, new rule highlighted three times a week, and rules discussed at weekly safety meetings. The consequent condition had very similar management involvement. A feedback graph was explained at an initial meeting, the graph was posted, feedback was provided three times per week, and supervisors discussed feedback at weekly meetings.

Changes recorded during the antecedent conditions were mixed. Two of four departments showed significant changes while the other two did not. During the consequence condition, all departments improved over baseline and over the antecedent levels of performance. A

survey afterwards indicated that 72% preferred the graph because it showed them how they were doing.

Earlier, Komaki et al. (1980) had undertaken a component analysis of feedback and training on safe performance. The experiment was carried out in a city vehicle maintenance division. The methodology included a multiple baseline with five conditions and reversal. The conditions tested were as follows:

- i) Baseline
- ii) Training only I (desired practices discussed, illustrated, and posted)
- iii) Training and feedback I (supervisors observe and graph feedback daily)
- iv) Training only II
- v) Training and feedback II

As discovered in the 1982 Komaki et al. experiment, training only produced slight improvements in safe performance, but training and feedback increased performance of safe behaviors significantly. Researchers concluded that training alone was not sufficient for improvement. During the second training only phase, performance actually declined. In the second training and feedback phase, improved performance required a minimal level of three feedback postings per week. This study brought about questions regarding the role of consistency in safety program maintenance and success, as well as the sustainability of behavioral safety programs over extended periods of time.

Geller and Lehman (1991) wrote a short summary of research in support of the Buckle-up Promise Card, a voluntary safety belt program. The cards have been used in numerous studies with significant numbers of volunteers increasing safety belt use in each study. Cards were compared favorably with longer lasting results than did incentive programs.

Consequences

Consequences are nearly as varied as antecedents and can include: incentives (monetary and non-monetary), punishment (with little success), coaching, and written or graphed feedback (most common).

Feedback

Feedback can be an effective, low-cost reinforcer. Komaki et al. (1978) used feedback to improve safe behavior in their ground-breaking study with great success. Feedback was charted showing the percentage of incidents performed safely. Figure 3 shows baseline, intervention, and reversal phase performance. In the makeup department, the baseline safe performance mean was 70%. During intervention this average rose to 90% and returned to 70% during reversal. In the wrapping department, baseline performance maintained constant around 78% even during the makeup department intervention. During the wrapping department intervention, the safe performance mean was consistently around 99.3%, dropping back to 72% in reversal. Five factors were attributed to the success of the feedback. The feedback was:

- 1) Positive (focused on safe performance)
- 2) Objective (outside observers)
- 3) Influenceable (employees knew how to improve)
- 4) Frequent (multiple times per week)
- 5) Public (results were known plant-wide)

Sulzer-Azaroff and Santamaria (1980) set up an industrial experiment in a small industrial plant to determine the reliability and generality of feedback on safety during intervention and reversal phases. A three component feedback package included: 1) feedback on the number and location of hazards, 2) specific suggestions for improvement, and 3) positive evaluation comments merited by accomplishments. Written and oral feedback was given to supervisors. The Vice-President of the company also participated in oral and written feedback from time to

time. As shown on a number of previous experiments, the feedback package successfully reduced hazards in the plant. The package was deemed as simple and efficient to implement, and thus was recommended for continuation. A four-month follow-up visit suggests that the program was ongoing.

Babcock et al. (1992) looked at a feedback program that had been established at a trauma facility for supervisory notices. Antecedent training and delivery of feedback forms to supervisory nurses resulted in little practice of the feedback function. It was not until the supervisory nurses began receiving feedback themselves that they too began providing feedback to nurses under their supervision. Several nurses noted that by providing feedback, they had themselves adhered to safety procedures more consistently. This may have also produced role-model effects with the general staff.

Feedback can increase the sensitivity of the worker to error-generating habits. Five characteristics of effective feedback were identified by Altman (1970):

- 1) Speed – prompt feedback may allow for error correction as well as provide opportunities for learning
- 2) Specificity – narrow focus on particular errors increases the likelihood of effectiveness
- 3) Accuracy – feedback error can have negative impacts
- 4) Content – delivery and information should be appropriate for the desired behavior results.
- 5) Amplitude – feedback must be salient, yet not disruptive.

Feedback frequency was studied by Chhokar and Wallin (1984) in the area of industrial and occupational safety. A stair-step variation of the reversal phase was used to study effects of training and goal-setting, and training, goal-setting, and feedback with varying levels of feedback frequency. Table 2 provides the safety performance percentages for each phase. Feedback every two weeks was found to be as effective as feedback once a week. By reducing the amount of feedback for the same return, a higher cost benefit ratio can be obtained.

Researchers cautioned against the unknown of reduced feedback on sustaining safe performance over long periods of time.

Incentives

Different incentive packages were developed for power punch press operators to test performance efficiency and injury avoidance in a study by McKelvey et al. (1973). Four pay scales were devised as follows and given to four different groups of workers:

- 1) Operators were paid \$4 for two hours of work and told that the number of presses would be recorded
- 2) Operator pay was dependent on the number of presses
 - (1) Less than 625 presses - \$1 for every half hour of work would be paid
 - (2) More than 625 presses - \$0.003 /press or \$7.50+ for two hours
 - (3) More than 675 presses - \$0.004/press or \$10.80+ for two hours
- 3) Same as group 2 except operator must be vigilant of warning light or press will shut down automatically for five minutes
- 4) Same as group 3 plus the addition of an accident warning regarding the removal of hands from the press – this activity will also automatically shut down the press for five minutes.

As expected, the ratio scale reinforcement (group 2) produced the greatest number of presses. Group 3, 4, and 1 followed in number of presses consecutively. The average number of accidents for each group was also recorded. Group 2, not surprisingly, had the highest average number of accidents recorded. Group 3 second highest and groups 4 and 1 were nearly equal with the lowest average accident rates. The message – incentives can produce gains in motivation, but if not carefully consequenced, motivation is at the risk of safety.

Test Impact by Observing, Recording and Evaluating

The final step in behavioral analysis is the measurement and evaluation of the program. As noted in the intervention section previously, numerous studies have been conducted to determine the effects of various antecedent and consequent intervention techniques. Those provided in this paper are only a small sampling of what have been conducted. In the late 1990's several books (Krause, 1997; Krause, 1995; Geller, 1998; and Miller, 1998) were published, covering the results found in hundreds of behavioral safety programs implemented by consulting firms around the country. The books present various techniques for effective programs that have resulted from the numerous implementations.

There are two other items that impact the effectiveness of behavioral safety programs which have yet to be covered. They are the role of management and long-term effects on program success. Komaki (1986) studied the behavior of managers and determined the outcome of their management styles on worker motivation. Managers who were ranked in the top of the group of subject managers in terms of motivating others, and those who ranked in the bottom were both studied. The effective group (top ranked) spent significantly more time collecting performance data than did those in the ineffective group (bottom ranked). No differences were noted in regard to the amount of time spent providing feedback, either positive or negative. Effective managers also spent time directly observing worker performance. Effective managers may inadvertently affect the outcome of many behavioral safety programs and should thus be studied along with other intervention mechanisms.

Perception surveys employed by Behavioral Science Technologies, Inc. (Krause, 1997) show that employees that believe their workplace maintains a high level of safety program maintenance have strong positive results. Those that do not see much safety program maintenance activities have less positive results.

The long-term effects of token economies were studied by Fox et al. (1987). Two mines implemented token programs, whereby tokens were given to workers for periods without lost-time injuries and accidents. Both mines achieved rates far below the national average over a 10-year period following the introduction of the incentive program. The results show that

behavioral safety programs can be administered for long terms with sustaining effects. There are some potentially damaging effects of token incentive programs that must be addressed. One is the non-reporting of accidents to maintain incentives. This can be reversed by making the token awards contingent upon reporting all accidents and equipment damage. Regression to the mean and damaging effects of life and injury can both lead to lessened accident rates over time with no further incentives.

Behavioral Safety in Transportation

Several applications of behavioral safety programs have been implemented in areas of transportation safety. One of the early accounts was written by Larson et al. (1980) regarding a reduction in police vehicle accidents through mechanically aided supervision. Tachograph recorders were early “black boxes” for automobiles. These early devices measured speed, distance traveled, non-movement, and use of emergency equipment in police cars. Anecdotal evidence suggests that these devices reduce the occurrence of accidents. This study evaluated the systematic use of the devices on a large-scale implementation and included a cost-benefit analysis. In 1975, the metropolitan Nashville police department had 341 reported crashes with over 75 injuries and a total cost of \$200,000. Over 200 vehicles were instrumented with tachographs mandated by the department. Three research phases were implemented: 1) baseline, 2) feedback, and 3) feedback plus inspections. In the second and third phases, officers had to defend inappropriate use of speed, lights, and non-movement. Figure 4 shows speeding behavior for the three phases. Noticeable reductions in speeding occurred only when the officers were held accountable by the inspection division.

Personal injury accidents were virtually eliminated during use of the tachograph. Accidents caused by negligence were also greatly reduced. The tachograph was used also as a form of objective performance measurement for individual officers as well as supplementing the disciplinary role of the department. On initiation, the officers viewed the recorders negatively, but this diminished over time. An estimate of the benefit to cost ratio indicated that the tachograph system appeared to be cost-effective.

Van Houten et al. (1985a, 1985b) looked at programs to reduce speed and accidents and also to increase driver yielding and pedestrian signaling with prompting, feedback and enforcement. In the pedestrian experiment, the intervention mechanisms included posting feedback on the percentage of motorists who yielded to pedestrians. Similarly, small signs were posted in the pedestrian area to promote engaging in appropriate crossing behavior by pedestrians. Enforcement, including warning tickets and feedback fliers, was sequentially introduced. The intervention doubled the number of motorists yielding to pedestrians and increased the number of pedestrians signaling their intention to cross.

The speed study utilized posted feedback on speeding and enforcement through warning tickets programs. Accidents were reduced in the direct vicinity of the posted feedback signs in both Canada and Israel. The results were significant. The introduction of the sign and enforcement condition led to a 65% reduction in injury accidents. Near-miss situations were not reported in this study as in the pedestrian study. This data element would have increased the validity of the reduction in accident numbers.

Finally, one last anecdote from E. S. Geller (1998) during a driving lesson with his daughter. Upon deciding that the seven hours of driver training that his daughter had received were insufficient, Geller sat down with his daughter and developed a critical behavior checklist for drivers (Figure 5). During a practice drive, Geller recorded safe and unsafe driving behaviors on the checklist. At the end of the drive, he told his daughter that she had completed 85% of the driving tasks safely. To his surprise, she asked what she had done wrong. He noted a couple of items of interest upon completion of this activity: 1) during the typical persons history, evaluations have mostly focused on mistakes, and therefore we always expect to find out what we did wrong; and, 2) people can be completely unaware that they have made a mistake.

Discussion

The application of behavioral safety techniques holds promise for safety programs in many disciplines. The programs can be low cost, and easy to implement and still maintain significant

levels of safe performance over time. By measuring the magnitude of behaviors that occur prior to accidents, companies can begin to curb incidents before they happen rather than after they have already become a statistic.

This is especially encouraging for transportation safety. By preventing accidents, many lives can be saved and injuries avoided. With the advent of high-tech event data recorders, researchers can obtain almost every interaction of the driver with the roadway and the vehicle. The real test will be to define critical behaviors and at-risk indicators based on all of the data obtained from these systems. Transportation safety programs must move to a new level, where evaluations do not focus on the consequence of the accident, but rather the preceding behaviors and hazardous situations.

Applications in work zone safety and driver training can also utilize the important feedback tools described herein. Studies in self-observation are needed to discern potential behavioral safety program effects on individual drivers. A potential exists for graduated licensing programs based on performance depicted with instrumented vehicles. Licenses could be withheld until the driver shows competence in safe driving performance. Further, licenses could be revoked for unsafe driving performance. As the one Ludwig and Geller study showed, young pizza delivery drivers were more susceptible to changes in responses for changes in policies. Behavioral safety could be the advent of a new era in transportation safety.

Finally, reliable behavioral controls that work hand-in-hand with engineering controls will afford the widest range of safe performance (Hopkins et al., 1986).

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Table 1*Classes of error for different behavioral levels*

BEHAVIORAL LEVEL	CLASSES OF ERROR	
	OMISSION	COMMISSION
Problem solving.	Failure to use information which would facilitate derivation of a solution. Giving up before a solution is reached.	Formulating erroneous rules or guiding principles. Acceptance of an inadequate solution as final. Perseverance on a problem when it is known to be insoluble.
Logical manipulation, rule using, and decision making.	Failure to identify or apply appropriate information, rules, or alternatives. Delaying a required decision.	Incorrect value weighting. Application of a fallacious or inappropriate rule. Making an unnecessary or premature decision.
Estimating with discrete or continuous responding (tracking).	Failure to respond to a super-threshold target change. Late response.	Responding to a sub-threshold target change. Premature response. Inadequate or excessive response. Wrong direction of control action.
Chaining or rote sequencing.	Omitting a procedural step.	Making a below-standard response. Inserting an unnecessary step. Misordering steps.
Sensing, detecting, identifying, coding, and classifying.	Failure to monitor the field. Failure to record or report a target or signal change.	Recording or reporting a target or signal change when none has occurred. Assignment of a target or signal change to the wrong class.

Table 2*Average Behavioral Safety Performance for Various Phases*

Phase	Performance (%)
A—baseline	65.21
B—training and goal setting	80.92
BC ₁ —training, goal setting, and feedback once a week	94.58
BC ₂ —training, goal setting, and feedback once in two weeks	96.78
RevB—reversal training and goal setting only	89.11
RevBC ₂ —training, goal setting, and feedback once in two weeks	93.91

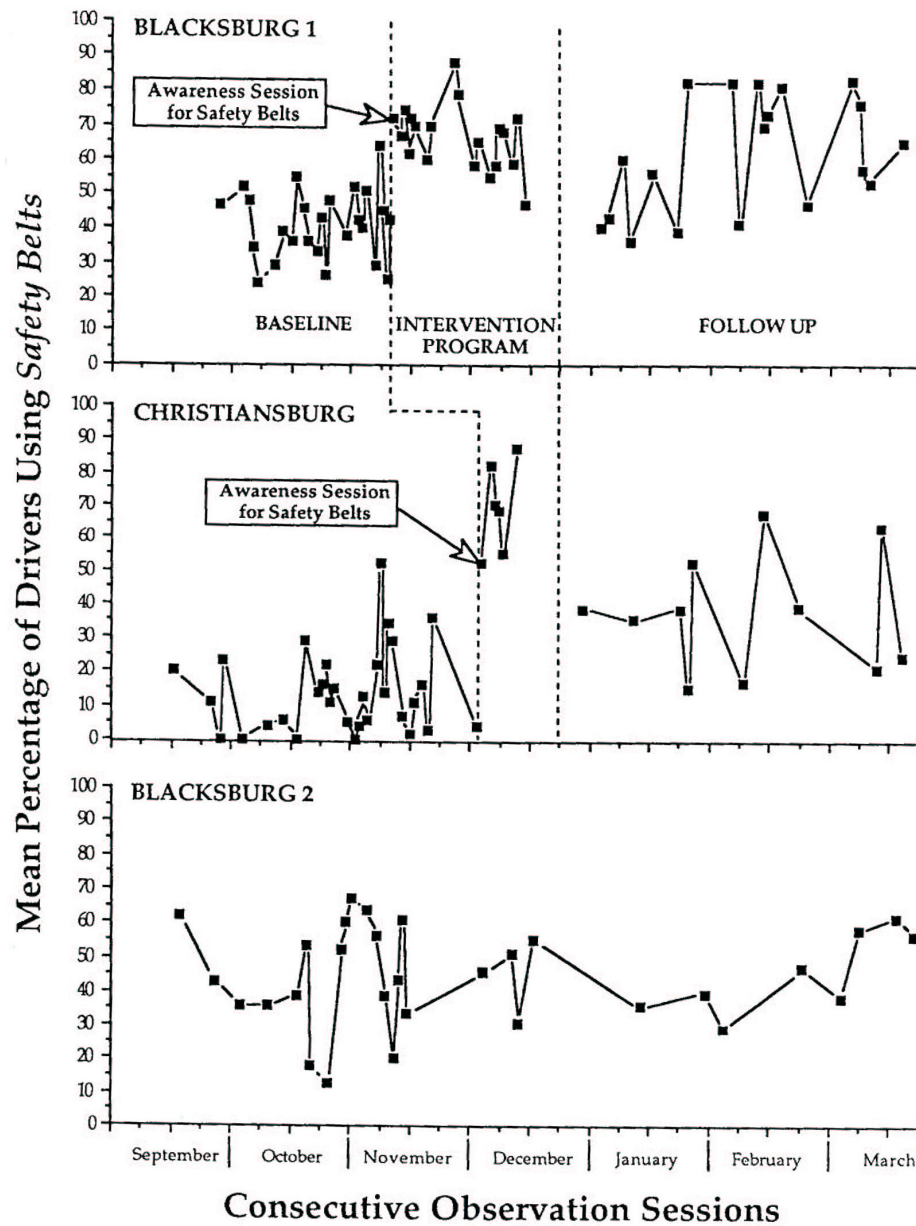


Figure 1. Mean percentage of safety belt use among pizza deliverers at the Blacksburg and Christiansburg sites during baseline, intervention, and follow-up phases (Ludwig and Geller, 1991, pp. 36)

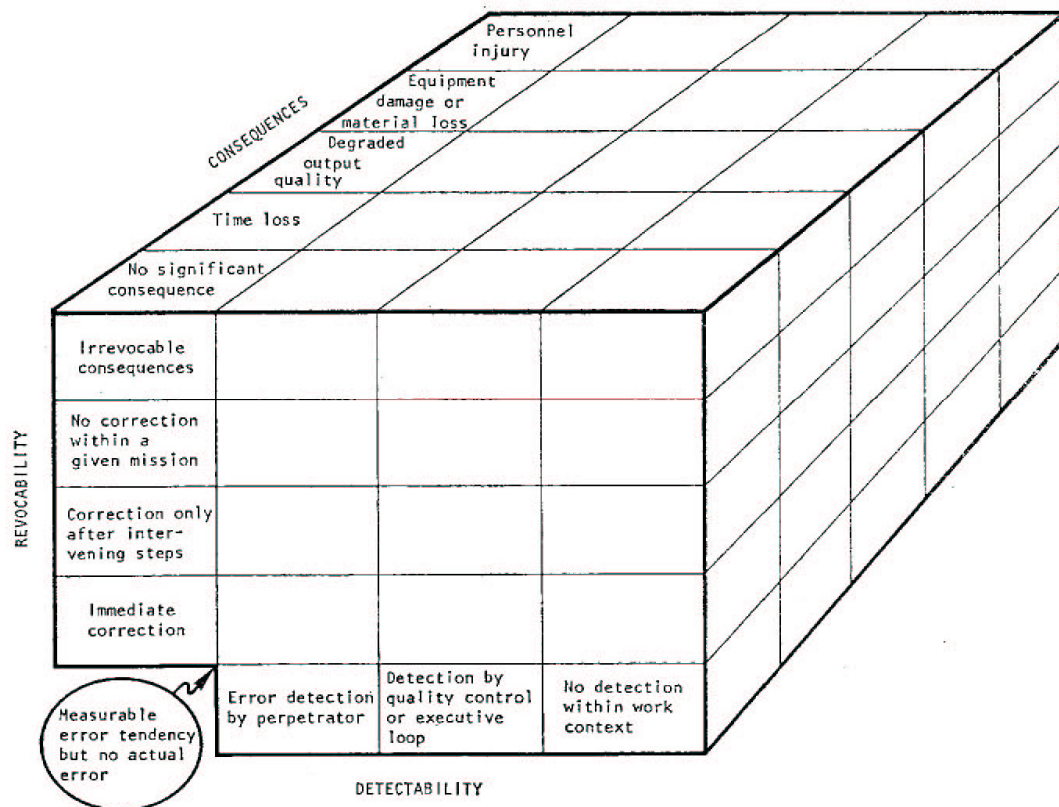


Figure 2. Detectability, Revocability, Consequence Matrix

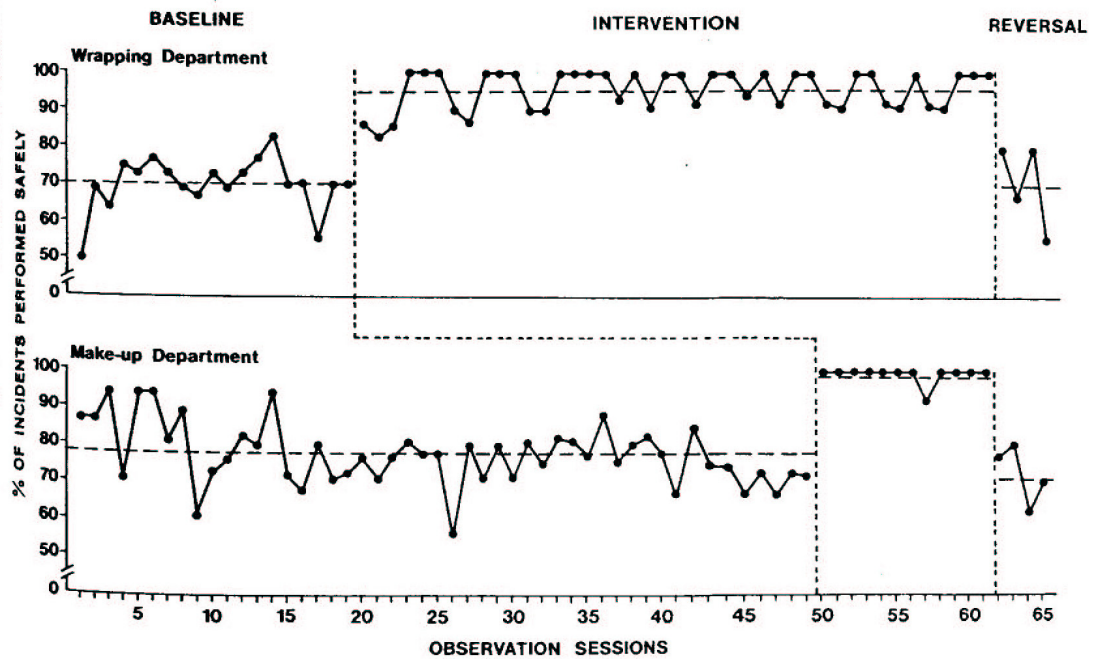


Figure 3. Percentage of items performed safety by employees in two departments of a food manufacturing plant during a 25-week period of time.

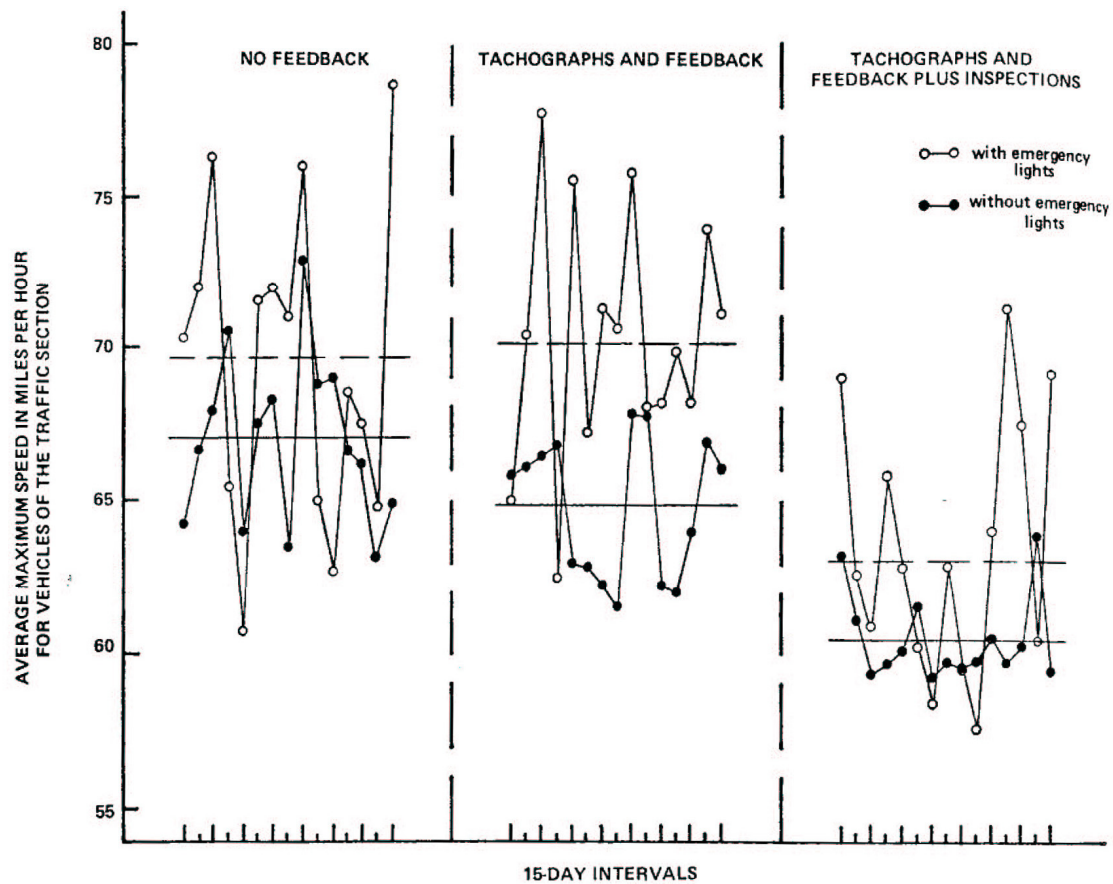


Figure 4. Mean daily maximum speeds for vehicles in the Traffic Section under both emergency and non-emergency driving situations.

Critical Behavior Checklist for Driving			
Driver:	Date:	Day:	
Observer 1:	Origin:	Start Time:	
Observer 2:	Destination:	End Time:	
Weather:			
Road Conditions:			
Behavior	Safe	At-Risk	Comments
Safety Belt Use			
Turn Signal Use			
Left turn			
Right turn			
Lane change			
Intersection Stop			
Stop sign			
Red light			
Yellow light			
No activator			
Speed Limits			
25 mph and under			
25 mph-35 mph			
35 mph-45 mph			
45 mph-55 mph			
55 mph-65 mph			
Passing			
Lane use			
Following Distance (2 sec)			
Totals			
$\% \text{ Safe} = \frac{\text{Total Safe Observations}}{\text{Total Safe} + \text{At-Risk Observations}} = \underline{\hspace{2cm}}$			

Figure 5. A critical behavior checklist to improve driving safety.

APPENDIX B

Consent Form and Certificate of Confidentiality

GEORGIA INSTITUTE OF TECHNOLOGY

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Title: COMMUTE Atlanta

Principal Investigator: Randall Guensler

Co-Investigators: Jennifer Ogle

Sponsor: Federal Highway Administration

Introduction/Background/Purpose:

We are asking you to be in a research study. The study will help us to understand how we can make the transportation system safer and more efficient. The people listed above are in charge of the study. Other people may help.

What is the purpose of this study?

This study will help us learn about Atlanta travel patterns and driving behavior.

How many subjects will participate in this study?

About 500 subjects in the Atlanta, GA area will participate.

How long will your participation last?

You will be in this study for 1 year. You may be asked to participate for two additional years, if the research continues and if you are willing to do so.

Study Procedures:

How does the study work?

We will install a device in your vehicle. It will record the time, position, speed, heading and the on/off status of brakes, windshield wipers, seatbelts and other vehicle systems as you drive. The data collected by the device will be automatically sent to the researchers each week. Whenever your vehicle is on the road the device provides information on travel time and traffic jams. This information can help planners figure out how to improve the transportation system.

We will pay for the installation of the device. We will arrange for an installer to come to your home or work location and install the device there. The device will be placed underneath one of the seats in your vehicle or underneath the dash. The equipment works by itself. You will not need to do anything to start or stop the equipment. The equipment will not affect normal operation, servicing, or maintenance of your vehicle. The equipment is about the size of a CD-changer. Passengers in the car will not see it. You will be able to see two small antennas for sending and receiving data. You will see them in the inside corners of your windows.

Our installers guarantee all of their work. Your vehicle will be returned in its original condition. If you discover any installation problems after installation of the device, please report them immediately to the installer. The installer will correct the problems regarding the installation of the device. GA Tech nor the installer will be responsible or liable for car repairs unrelated or not attributable to the device.

The equipment will stay in your vehicle for 1 year. If you plan to sell or trade-in your vehicle, you will need to contact the Principal Investigator, Randall Guensler. He will arrange for the equipment to be taken out of your vehicle. We will have the device put back in your new vehicle so you may continue to be in the study. At the end of the study, the equipment will be removed from your vehicle by the installer at your home or work location.

We will contact you every 6 months during the three-year study period. You will be asked a set of standard questions. Each interview will take about one-half hour.

We ask for your permission to view your driver history records. These will be obtained from the Department of Motor Vehicle Safety. We will only use this information to determine risk factors for the total group of 500 subjects. Information we collect may include past accident records and traffic violations. This information will not be given to anyone else.

What are the possible benefits?

There is a personal benefit that you will receive if you want. The device has a satellite antenna. We will help the police department find the vehicle if you call and tell us that it has been stolen.

Theft Recovery

If your vehicle is stolen during the study period call the police and the study Hotline to report the theft. We can try to contact the vehicle and obtain its current position through on-board equipment. We can relay this information to the police. It may help find your vehicle. This is a research project. The operation of the theft recovery feature cannot be guaranteed. Georgia Tech and associated research partners cannot take responsibility in the event that this system does not work.

Potential Risks:

What are the possible risks?

We know of no physical risks of being in this study.

We have no control over your normal risk of being involved in an accident while driving.

Confidentiality:

How will your privacy be protected?

We will keep all facts about you private.

Whenever we can, we will use a study number rather than your name on study records. We will keep this informed consent document and any driving history records that identify you by name or in any other way in locked storage at the DRIVE Atlanta Laboratory at Georgia Institute of Technology, 790 Atlantic Drive, SEB 220, Atlanta, GA 30332-0355. Your name and other facts that might point to you will not appear when we present or publish the results.

We will do everything we can to protect your privacy. To assist us in protecting your privacy, we have obtained a Certificate of Confidentiality from the National Institutes of Health. This Certificate means that researchers cannot be forced to disclose information that would identify you. This includes identifying information about your vehicle, such as the vehicle identification number. Your personal information will be protected by the full extent allowed by law.

Georgia Institute of Technology Institutional Review Board, the sponsor of this study, Federal Highway Administration, and the governmental agencies that are responsible for protecting people in research studies, have the right to review study records. This is to make sure that this research activity is being conducted as it should be.

You may voluntarily release information about yourself and your involvement in this research. If you agree to allow release of your data to any party, we can no longer withhold your information by means of the Certificate of Confidentiality. If you voluntarily tell us during an interview that you are going to cause serious harm to yourself or others, we would have to disclose this information to an appropriate party (for example the police).

In Case of Harm/Injury

If you are injured as a result of being in this study, please contact Randall Guensler. He is the Principal Investigator. His telephone number is 404-894-0405. Your parent/guardian has also been given this information. Neither the Principal Investigator, Georgia Institute of Technology nor any associated research partners have planned for payment of costs related to any accident or medical emergency that happens while you are participating in this study.

Contact Information

If you have any questions about the research, you can contact Randall Guensler, the Principle Investigator, at:

Randall Guensler, Ph.D.
Associate Professor
Georgia Institute of Technology
School of Civil and Environmental Engineering
790 Atlantic Drive
Atlanta, GA 30332-0355
404-894-0405
404-385-2375 fax
email: randall.guensler@ce.gatech.edu

If you have any questions about your rights as a research volunteer, you may call or write:

Alice Basler
Compliance Administrator
Office of Research Compliance
Georgia Institute of Technology
400 Tenth Street, Rm. 239
Atlanta, GA 30332-0420
Voice:(404) 894-6942
email: alice.basler@osp.gatech.edu

Signature Page

Subject's Rights

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will get a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Subject's Agreement:

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

Signature of Research Subject

Date

Printed Name of Research Subject

Signature of Person Obtaining Consent

Date

Printed Name of Person Obtaining Consent



DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

National Institutes of Health
National Institute of Mental Health
6001 Executive Boulevard
Bethesda, Maryland 20892

October 21, 2004

Randall Guensler, Ph.D.
Associate Professor
School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Drive
Atlanta, GA 30332-0355

Dear Dr. Guensler:

Enclosed is the Confidentiality Certificate protecting the identity of research subjects in your project entitled, "Commuter Choice Insurance Incentive Value Pricing Program" aka "Commute Atlanta". Please note that the Certificate expires on June 30, 2007.

Please be sure that the consent form given to research participants accurately states the intended uses of personally identifiable information and the confidentiality protections, including the protection provided by the Certificate of Confidentiality with its limits and exceptions.

If you determine that the research project will not be completed by the expiration date, June 30, 2007, you must submit a written request for an extension of the Certificate three (3) months prior to the expiration date. If you make any changes to the protocol for this study, you should contact me regarding modification of this Certificate. Any requests for modifications of this Certificate must include the reason for the request, documentation of the most recent IRB approval, and the expected date for completion of the research project.

Please advise me of any situation in which the certificate is employed to resist disclosure of information in legal proceedings. Should attorneys for the project wish to discuss the use of the certificate, they may contact the Office of the NIH Legal Advisor, National Institutes of Health, at (301) 496-6043.

Correspondence should be sent to:

Ms. Olga Boikess
Office of Resource Management
National Institute of Mental Health
6001 Executive Boulevard, Room 8102 (MSC 9653)
Bethesda, Maryland 20892-9653
Telephone: (301) 443-3877
Fax: (301) 443-2578

Sincerely,


Olga Boikess

Enclosure

CONFIDENTIALITY CERTIFICATE

MH-04-135

issued to

Georgia Institute of Technology

conducting research known as

“Commuter Choice Insurance Incentive Value Pricing Program”

aka

“Commute Atlanta”

In accordance with the provisions of section 301(d) of the Public Health Service Act 42 U.S.C. 241(d), this Certificate is issued in response to the request of the Principal Investigator, Randall Guensler, Ph.D., to protect the privacy of research subjects by withholding their identities from all persons not connected with this research. Dr. Guensler is primarily responsible for the conduct of this research, which is supported by Georgia Department of Transportation.

Under the authority vested in the Secretary of Health and Human Services by section 301(d), all persons who:

1. are enrolled in, employed by, or associated with the Georgia Institute of Technology and its contractors or cooperating agencies, and
2. have in the course of their employment or association access to information that would identify individuals who are the subjects of the research pertaining to the project known as “Commuter Choice Insurance Incentive Value Pricing Program” aka “Commute Atlanta”,

are hereby authorized to protect the privacy of the individuals who are the subjects of that research by withholding their names and other identifying characteristics from all persons not connected with the conduct of that research.

This behavioral research study investigates whether or not converting fixed automotive insurance costs into variable driving costs – i.e. a per-mile insurance pricing system – causes subjects to modify their driving patterns in an effort to reduce their total insurance rates. This study is an instrumented vehicle research program funded by the Federal Highway Administrations (FHWA) Value Pricing Program through the Georgia Department of Transportation. Subjects are members of some 250 households and their employers. The project includes the parallel collection of instrumented vehicle data, household socio-demographic surveys, two-day travel diaries, and employer commute options surveys.

A Certificate of Confidentiality is needed because sensitive socio-economic information, information about mental health, substance use, illegal activity and psychological well-being will be collected during the course of the study. The certificate will help researchers avoid involuntary disclosure that could expose subjects or their families to adverse economic, legal, psychological and social consequences.

All subjects will be assigned a coded number and identifying information and records will be kept in locked files.

This research is underway, and is expected to end on June 30, 2007.

As provided in section 301 (d) of the Public Health Service Act 42 U.S.C. 241(d):

"Persons so authorized to protect the privacy of such individuals may not be compelled in any Federal, State, or local civil, criminal, administrative, legislative, or other proceedings to identify such individuals."

This Certificate does not protect you from being compelled to make disclosures that: (1) have been consented to in writing by the research subject or the subject's legally authorized representative; (2) are required by the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 301 et seq.) or regulations issued under that Act; or (3) have been requested from a research project funded by NIH or DHHS by authorized representatives of those agencies for the purpose of audit or program review.

This Certificate does not represent an endorsement of the research project by the Department of Health and Human Services. This Certificate is now in effect and will expire on June 30, 2007. The protection afforded by this Confidentiality Certificate is permanent with respect to any individual who participates as a research subject (i.e., about whom the investigator maintains identifying information) during any time the Certificate is in effect.

Date: October 21, 2004


William T. Fitzsimmons
Executive Officer

APPENDIX C

Commute Atlanta Recruitment Package

<Participant Name>
<Participant Address>
<Participant City>, GA <Participant Zip>

<Date>

Dear <Participant Name>,

The Federal Highway Administration, Georgia Department of Transportation, and the Georgia Institute of Technology would like to thank you for agreeing to participate in the COMMUTE Atlanta Program. You and your family, along with 275 additional households in and around Atlanta, are providing much needed data on the travel patterns and driving characteristics of Atlanta drivers.

With better information on where, when, and under what conditions people drive in Atlanta, transportation planners and engineers will be able to more effectively plan the future of our transportation system. The study will help us to understand how we can make the transportation system safer and more efficient. Participation of volunteers is essential to meeting these goals.

The COMMUTE Atlanta study is being conducted by the Georgia Institute of Technology. During your recent phone call with our partners at NuStats, you scheduled tentative installation appointments. Within the next few days, a research assistant will call to remind you of your installation date and time. To provide you with further information on the project, we have included a project brochure, a contact card (with the hotline telephone number), installation appointment card, and consent form(s). The consent form(s) need to be filled out by the primary driver of each vehicle that will be in the program. You must provide a completed consent form to the installer prior to the installation of the equipment. If you misplace your form, the installers will be able to provide you with another one.

We appreciate you taking the time to help with this very important project. If at any time you have any questions or concerns about the study, please feel free to contact us at the COMMUTE Atlanta Hotline 404-385-2376.

Sincerely,

Randall Guensler, Ph.D.
Associate Professor

Why should you participate?

There are 2 reasons why you should participate in this study:

1. **Theft Recovery***: If your vehicle were to be stolen, the on-board equipment could provide your vehicle's position. This information can aid the police in locating your vehicle.
2. **Help Planners Gain Knowledge**: To provide transportation planners the opportunity to learn about regional travel patterns, congestion levels throughout Atlanta, and driving behavior of Atlanta drivers.

**Due to the nature of the research program, we cannot guarantee the theft recovery features.*

YOUR PRIVACY...

The information that we collect will remain confidential. To assist us in protecting your privacy, we have obtained a Certificate of Confidentiality from the National Institutes of Health. This Certificate ensures that researchers cannot disclose information that would identify you.

COMMUTE Atlanta
is funded by:

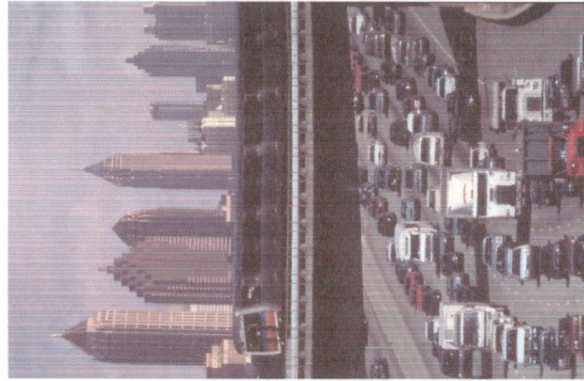


For more information about the
DRIVE Atlanta research program,
please call our hotline at:

404-385-2376



COMMUTE Atlanta



Saving Lives and Saving Time

COMMUTE Atlanta: What is it?

Do you recall hearing that 60% of households in the US were tuned into the Super Bowl game this year? Did you ever wonder how they know what you watch on television? The answer – 5,000 households nationwide volunteer to have their television viewing monitored by Nielsen Media Research with a People Meter recording device. The People Meter collects information on what is being watched, for how long, and who is doing the watching. These results are then used to determine nationwide statistics.

Much like Nielsen collects information on television viewing habits, Georgia Tech and the Federal Highway Administration will collect information on Atlanta's driving habits. In a research study entitled "COMMUTE Atlanta", Georgia Tech researchers will be monitoring the travel behavior of 500 Atlanta drivers with a similar recording device called the GT Trip Logger. Georgia Tech



researchers are interested in information such as where travel occurs, how long it takes, and who is doing the traveling. COMMUTE Atlanta will help planners and researchers understand vehicle use in the Atlanta region, which is essential to better utilization of scarce transportation resources.

What does your participation involve?

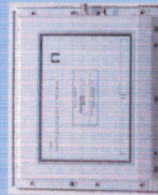
Your household was recently selected to participate in the COMMUTE Atlanta program research program. There are five parts to participation:

1 CONSENT

Your participation in this study is voluntary. To ensure that you have sufficient information on the details of the project, you will be asked to read and sign a consent form. Minors will be required to sign an assent form and have their parent/guardian sign a parental permission form.

2 INSTALLATION

We have contracted with professional installers to equip your vehicle with a data collection device. The device will be located under the seat of your vehicle with all cabling hidden from view. Installs can be done at all local HiFi Buys locations or on-site at your home/work.



3 DRIVE

Once the unit is installed in your vehicle, you will continue to drive as normal. The device turns on and off automatically with your vehicle ignition. You will not be required to input anything into the device. The recorded data will be downloaded over a cellular connection every week. Starting your vehicle once a week is recommended to ensure battery charge.

4 REPORT

If you will be trading, selling, or retiring your car from service please give us a call at the hotline to let us know. We will gladly uninstall and reinstall the data collection device in your new car. Please also call if you should happen to be the victim of a theft, or involved in a crash.

5 FOLLOW-UP

We will contact you approximately every six months during the two year study period. This follow-up will be used to find out if there were any major changes in your travel habits and to update you on the status of the project.



COMMUTE*Atlanta*

Hotline: (404) 385-4097

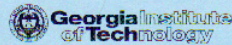
Georgia Tech/CEE
790 Atlantic Drive
Atlanta, GA 30332-0355
Fax: (404) 894-2278

Principal Investigators:
Randy Guensler and Jennifer Ogle

2003 **COMMUTE**Atlanta Study

Personal Two-Day Travel Diary for:

Sponsors Include:



*Survey conducted by NuStats on behalf of the
Georgia Institute of Technology, Georgia Department of Transportation
and the Federal Highway Administration.*

Questions? Please call NuStats at:
1-877-261-4621



Diary Instructions

Use this diary to record **PLACES** visited, **TRIPS** made, and the **ACTIVITIES** you did at each **PLACE**. Specifically, you should record the following, in as much detail as possible:

- ✓ **PLACES** visited (place name; exact address and/or cross-streets, county, city, and zipcode are critical for assessing areas with traffic congestion.)
A **PLACE** is any location you travel to whether it's for just a few minutes (such as a gas station, drive-through window, dropping your child off at school, etc.) or for many hours (work, attending a sporting event, etc.)
Important note: If you ride the bus or train, please record each bus stop or train station where you got on or off as a separate **PLACE** (and record the address or cross-streets, times, activities, etc.)
- ✓ **TIMES** you began and ended each trip (be as exact as possible - to the minute helps us assess how long it takes to get from one place to another.)
Each travel day begins at 3am the day of travel and ends at 2:59am the next day.
- ✓ **MODES** or how you traveled to each place you visited. Identify the code for your travel mode on the TRAVEL MODES LIST and write it in the box provided under question C. Following is an example:

TRAVEL MODES LIST is on the inside of flap

Codes

TRAVEL MODES LIST

Use these codes to answer question **C**
Specify if you can't find a matching code.

Auto/Truck/Van:

1	Drove
2	Passenger

C **HOW did you get to this PLACE?** (Write code from TRAVEL MODES LIST - on flap →)

Mode: 1

(One response only)

TRAVEL MODES LIST

Use these codes to answer question **C**
Specify if you can't find a matching code.

Auto/Truck/Van:

- 1 Drove
- 2 Passenger

Transit:

- 3 Local bus (MARTA)
- 4 Local bus (CCT, GCT, GRTA, etc.)
- 5 Heavy rail (MARTA)
- 6 Dial-a-Ride/Paratransit
- 7 School bus

Other modes:

- 8 Taxi/Shuttle bus/Limousine
- 9 Motorcycle/Moped
- 10 Bicycle
- 11 Walk
- 12 Intercity bus
(Greyhound, Trailways, etc.)
- 13 Airplane
- 14 Intercity train (AMTRAK)
- 97 Other: (Write code & specify in diary)

- ✓ **ACTIVITIES** or **WHAT YOU DID** at each place. Use the **ACTIVITY LIST** to help you. First write the code for the main activity you did in the first box and then write in the codes for any other activities you did in the other boxes. The following example is helpful:

ACTIVITY LIST

Use these codes to answer question **F**
Specify if you can't find a matching code.

Codes

- 1 Eating/preparing meals/dining out/
drive-through
- 2 Entertainment (watching TV, theater,
spectator sports, dance club, etc.)

F What **ACTIVITIES** did you do? (Write code from **ACTIVITY LIST** - on flap →)

Main Activity:
(One response only)

Other Activities:
(Record all that apply)

Specify if you can't find a matching code.

The day after your travel days, a professionally trained NuStats interviewer will call to collect your household's information. For anyone who is unable to complete a diary, we ask that a parent or other adult complete the diary for them.

We guarantee that the information you provide will remain entirely confidential. We do not sell phone lists to anyone. The information from all participants will be grouped for analysis and used by the state and your local governments to help plan the future of transportation in your area.

Questions? Please call 1-877-261-4621

**Thank you for helping shape the
future of transportation in Atlanta!**

ACTIVITY LIST

Use these codes to answer question **F**
Specify if you can't find a matching code.

- 1 Eating/preparing meals/dining out/
drive-through
- 2 Entertainment (*watching TV, theater,
spectator sports, dance club, etc.*)
- 3 Visiting with friends/relatives
- 4 Working
- 5 Work related business (*sales call,
meeting, errand, conference, etc.*)
- 6 School (*attending classes*)
- 7 Incidental shopping (*gas, groceries,
housewares, medicine, etc.*)
- 8 Major shopping
(*furniture, clothes, auto, etc.*)
- 9 Watching children
- 10 Household work/outdoors work
- 11 Fitness/Exercising (*working out,
walking, soccer, aerobics, tennis, etc.*)
- 12 Recreation
(*vacation, camping, sightseeing, etc.*)
- 13 Medical/dental appointment,
treatment, procedure
- 14 Community meetings, political/civic
event, public hearing, voting, etc.
- 15 Worship/religious meeting
- 16 ATM, banking, post office, utilities
- 17 Waiting for transportation/changing
modes of transportation
- 18 Drop-off/pick someone up
- 97 Other Activity
(*Write code & specify in diary*)

Day One

PLACE

1

DAY ONE - BEGIN HERE

For this diary, each day begins at 3am.

Most people are home asleep at 3am. If this is the case with you, then check **"My Home,"** record the exact time you left for the first time, and write all the activities you did before leaving.

IF YOU RIDE THE BUS OR TRAIN:

Please record each bus stop or train station where you got on or off as a separate **PLACE** (record the address or cross-streets, times, activities, etc.)

A WHAT is this PLACE?

☐ My Home

☐ My School

☐ My Primary Workplace

☐ Another PLACE

Name of Place (if any) or nearest landmark (e.g. building name)

Street Address

City

County

Zip Code

&

Nearest Cross Streets

B What TIME did you LEAVE this PLACE?

(Please be as exact as possible)

: am / pm

C What ACTIVITIES did you do? (Write code from ACTIVITY LIST - on flap →)

Main Activity:

(One response only)

--	--

Other Activities:

(Record all that apply)

--	--

--	--

--	--

D Was this your ONLY PLACE for the day? ☐ NO → Next PLACE

☐ YES → Begin Day 2 at 3am

Day One**PLACE
2****A WHAT is this PLACE?**

- ☐ My Home ☐ My School
☐ My Primary Workplace ☐ Another PLACE

Please provide as much of the address as possible:

Place name: _____

Address/City: _____

County/Zip: _____

Cross streets: _____

B What TIME did you ARRIVE?

(Please be as exact as possible)

: am / pm

C HOW did you get to this PLACE? (Write code from TRAVEL MODES LIST - on flap →)

Mode:

(One response only)

--	--

D If you got there by:

Auto/Truck/Van
Modes: 1 - 2

Total number of people
traveling with you?

--

Number of household
members traveling
with you?

--

Public Transit
Modes: 3 - 5

Which bus or rail train
route did you use?

Bicycle or Walk
Modes: 10 - 11

How many miles
did you travel?

--

E What TIME did you LEAVE?

(Please be as exact as possible)

: am / pm

F What ACTIVITIES did you do? (Write code from ACTIVITY LIST - on flap →)

Main Activity:

(One response only)

--	--

Other Activities:

(Record all that apply)

--	--

--	--

--	--

G Was this your LAST PLACE for the day? ☐ NO → Next PLACE

☐ YES → **Begin Day 2
at 3am**

EXTRA PLACES - Travel Day One

If you used all of the previous Day One pages, use the chart below to keep information on other places you went to.
Don't forget to record your exact times!

PLACE #	A WHAT is this PLACE? <small>(provide as much address info as possible)</small>	B What TIME did you ARRIVE? <small>(record exact times)</small>	C HOW did you get there? <small>(use MODE LIST)</small>	E What TIME did you LEAVE? <small>(record exact times)</small>	F What ACTIVITIES? <small>(use ACTIVITY LIST)</small>
11		: am/pm		: am/pm	
12		: am/pm		: am/pm	
13		: am/pm		: am/pm	
14		: am/pm		: am/pm	
15		: am/pm		: am/pm	
16		: am/pm		: am/pm	
17		: am/pm		: am/pm	
18		: am/pm		: am/pm	
19		: am/pm		: am/pm	
20		: am/pm		: am/pm	

APPENDIX D

Georgia Tech Trip Data Collector Equipment Specifications

Georgia Tech Trip Data Collector

Georgia Institute of Technology specified functional and operational performance characteristics and assisted in the development of this data collector specifically for comprehensive vehicle trip data collection and analysis. The TDC is being used for projects funded by federal and state agencies to capture and transmit relevant vehicle trip data, GPS coordinates, mileage, start and stop times, on-board computer data, seat belt use, etc.

The TDC includes a digital cellular transceiver capable of sending data through low cost short message service (SMS) or larger volumes of data through circuit switched technology. The GPS provides accurate data at intervals defined through customer applications. Four input and output sensors record seat belt use, brake use, and other user defined sensors.

The TDC can optionally be interfaced with the vehicles onboard data bus for further data capture of the vehicles engine parameters and performance.



Benefits:

- Wireless data communications capabilities with TDMA digital cellular transceiver.
- Low cost data transmission capabilities using SMS and circuit switched technologies
- Four user defined input sensors for detecting and recording various vehicle conditions.
- Powerful 386 CPU with 32MB of memory, and capable of field and remote upgrades.
- Backup battery with smart charging technology.
- Internally mounted active GPS and cellular antennas.
- Rugged enclosure with easy installation and removal.

Features

- Powerful 386 25MHz microprocessor with 4 MB flash memory, 8 MB DRAM
- Large 16 MB Removable Compact Flash
- Battery Powered real time clock
- High speed transmission rates of up to 9600 baud
- Low power consumption, less than 50 milliamps
- 12 hour long life battery backup, 7.2 volt NiCad
- Easily hidden internally mounted GPS and cellular antennas
- Four user defined Inputs and outputs for custom applications
- 6 Serial Ports
- 800 MHz TDMA digital transceiver
- SiRF Star II GPS
- Easily installed extruded aluminum housing

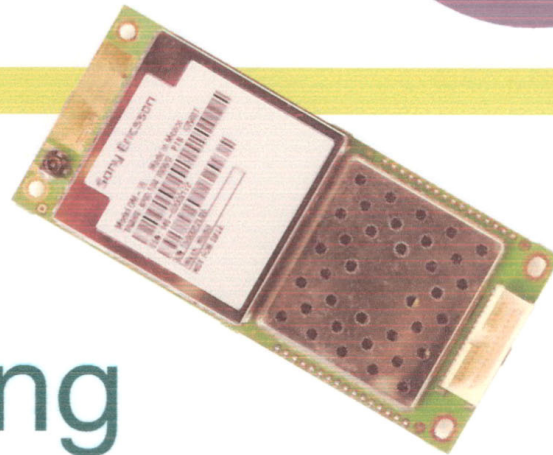
Technical Specifications

Standards:	FCC Part 15
Data Rate:	9600 Baud
CPU:	386 25 MHz Intel 8 MB DRAM 4 MB Flash 16 MB Compact Flash 6 Serial Ports CPLD Mixed Signal Flash MCU with 12-bit A/D 1024 Byte FIFO
Dimensions:	8.5" (H) x 6.25" (W) x 2.2" (D)
Unit Weight:	4 lbs.
Power:	13.8 volts DC 3 amps peak Regulated at 3.5 and 5 volts
Temperature Range:	-20° to 85° C
Backup Battery Life:	Up to 12 Hours in standby

Sony Ericsson



DM15



Redefining Ruggedness in TDMA Communications

- Single Band Dual Mode
AMPS & TDMA 800 MHz
- API and Mount compatible
with Sony Ericsson GSM and
CDMA units
- SMS MO/MT
- Analog and PCM Digital
Audio
- Fax, Group 3
- Automotive Environment
- -40°C to +85°C Operation
- Single Voltage Operation
- QS 9000 Manufacturing

The Sony Ericsson DM15 Cellular Communication Unit establishes new industry standards for ruggedness, performance, reliability, footprint, power consumption, and flexibility in digital communications technology.

Evolution of the robust and successful DM10, the DM15 offers the same functional features as its predecessor, virtually eliminating the requirement for application reengineering from DM10 customers.

While the significant backward compatibility is a definite strength of the new unit, the market-based enhancements introduced in the DM15 easily and quickly enable substantial evolution of the end-user application.

The benefits from these enhancements open doors to new revenue opportunities for both the established solution integrator as well as the newcomers to the dynamic world of machine-to-machine communication.

M2M Com Product Unit of Sony Ericsson Mobile Communications is ISO-9001 Certified.

DM15

Feature highlights

- Dual Mode (TDMA/AMPS 800 MHz)
- Digital PCM and Analog Audio
- Vocoder: Full Duplex FR/EFR
- Echo Cancellation and Noise Suppression
- SMS (MO/MT)
- OTA Activation and Provisioning:
- AT Command Set: ITU V.24 with Enhancements
- FAX, Group 3
- IS 130/135 Async Data
- Aeris MicroBurst®/V-Burst compatible
- Carrier Service Support
 - Caller ID
 - Call Forwarding
 - Call Waiting
 - 3-Party Conference Calling
 - Service Indicator
 - Message Waiting
 - Call Barring

Power

- Single Power Supply Operation
- 5 Volts, +/-10%

Developer's Kit

- CD-ROM
 - Extensive Integration Manual
 - Software
- Developer's Platform
- Antenna
- Power Supply
- Cables

Network standards

- Standards and supported classes
 - TDMA Class IV
 - AMPS Class IV
- Aeris MicroBurst®, Class IV
- Air Interfaces
 - TIA/EIA-136
 - TIA/EIA-553

Connections

- Standard 40-pin DIP connector for board-to-board or Ribbon
- Compatible with multiple types surface mount and end launch RF connectors

Physical characteristics

- 103 x 46.5 x 13mm
- 45 grams

Environmental

- -40°C to +85°C Operating Temperature Range
- Shock Resistance 20G Half Sine, 11ms

Quality

- M2M Com Product Unit of Sony Ericsson Mobile Communication is ISO-9001 Certified
- Manufactured to QS9000 Quality Standards



Sony Ericsson

Sony Ericsson Mobile Communications (USA) Inc.
7001 Development Drive, PO Box 13969, Research Triangle Park, NC 27709 USA
Email: module.support.usa@SonyEricsson.com



SiRFstarIIe/LP Chip Set A Low Power GPS Chip Set for Consumer Products



ARCHITECTURE HIGHLIGHTS

Industry Leading GPS Performance

- Builds on high performance SiRFstarIIc
- Architecture supports user task integration
- Signal acquisition using 1920 time/frequency search channels
- SBAS (WAAS and EGNOS), and DGPS support
- Multipath-mitigation hardware
- Cold Start under 45 seconds

Low Power

- Under 175 mW at full power
- TricklePower™ mode reduces power to under 60 mW
- Adaptive TricklePower intelligently switches between full and TricklePower.
- Push to fix reduces power by as much as 98%

Maximizes GPS Position Availability

- SingleSat™ updates in reduced visibility
- Superior urban canyon performance
- FoliageLock™ for weak signal tracking

FAMILY HIGHLIGHTS

GSP2e/LP - Flexible Digital IC

- Microprocessor throughput measured at up to 40 MIPS
- 8k of cache for improved throughput
- On-chip 1Mb SRAM for GPS navigation
- Integrated high-precision Real-Time Clock
- Extensive GPS receiver peripherals
- 2 UARTS, high speed serial bus, battery backed SRAM, >40 GPIO,

GRF2i/LP - Low Power RFIC

- On-chip VCO and reference oscillator
- Integrated LNA
- Uses less than 30 mA's of current
- Simplified digital interface

GSW2 Modular Software

- Easily integrated into existing systems
- 95% CPU throughput available for user tasks
- Tunable performance in all applications
- Robust development environment
- Compatible with SiRFloc and SiRFxtrac

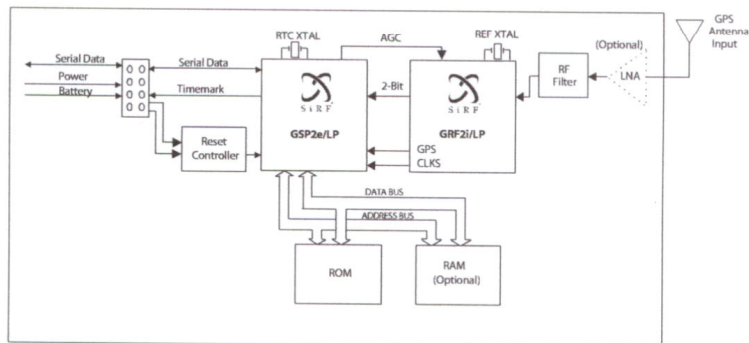
SiRFstarII ARCHITECTURE

SiRFstarIIe/LP architecture sets the standard for high volume GPS performance. The SiRFstarIIe/LP still uses 1,920 correlators and 12 channels to provide fast acquisition and re-acquisition times, while keeping peak current to under 65 mA. TricklePower extends battery life even further by reducing average current to under 20mA. Now superior performance features like SingleSat, SnapLock, and FoliageLock are available using less power.

The chipset consists of the GSP2e/LP, a highly integrated digital chip with 40 MIPS of processing power and the GRF2i/LP, a lower power version of the GRF2i integrated front end. The GSW2 software completes the package providing flexible system architecture for stand-alone GPS based products. The SiRFstarIIe/LP also supports SiRF's high sensitivity stand alone software, SiRFxtrac and multi-mode software, SiRFloc. When low power, low cost, and high performance matter SiRFstarIIe/LP is the best solution.



SiRFstarIIe/LP BLOCK DIAGRAM



TECHNICAL SPECIFICATIONS

Position Accuracy	
Autonomous	<10m
WAAS	<5m
Beacon DGPS	<2.5m
Receiver	
Tracking	L1, CA code
Channels	12
Max. Update Rate	10Hz
Sensitivity	-172dBW
Max. Altitude	<60,000 ft
Max. Velocity	<1,000 knots
Protocol Support	NMEA, SiRF Binary
Acquisition	
Reacquisition Time	100msec
SnapStart	<3sec
Hot Start	<8sec
Warm Start	<38sec
Cold Start	<45sec
Power	
Full Power (S2AM Module)	<175mW
TricklePower (1Hz)	<60mW
Voltage	2.7-3.3V (5V I/O capable)
Processor	
Processor Type	ARM7/TDMI
Processor Speeds	6MHz, 12.5MHz, 25MHz, 49MHz
Data Bus	16 Bit or 32 Bit
Ports	>40 GPIO

Specifications above are for GSW2

WORLDWIDE SALES OFFICES

SiRF California
+1 (408) 467-0410
sales@sirf.com

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tomlin@sirf.com

APPLICATIONS

The SiRFstarIIe/LP is a flexible low-power GPS chip set that integrates into a postage-stamp sized receiver. It works well where GPS is the main function such as handheld GPS, marine GPS, or personal locators or where the design calls for stand-alone GPS functionality such as GPS integrated into the batteryback of a cell phone or in an add on compact flash card. The excess processing power can be used for user tasks such as running an LCD or controlling an Automatic Vehicle Location module.

CHIP ORDERING CONFIGURATION

RF CHIP PACKAGES

Chip Name	Chip PN	Package
SiRFstarII GRF2i/LP	GRF2i/LP-0210	LQFP, 48 pin
SiRFstarII GRF2i/LP (QFN)	GRF2i/LP-0214	(LPCC), 32 pin

DIGITAL CHIP PACKAGES

Chip Name	Chip PN	Package
SiRFstarII GSP2e/LP	GSP2E/LP-7450	TQFP, 16-bit, 100 pin
SiRFstarII GSP2e/LP	GSP2E/LP-7451	BGA, 16-bit, 144 pin
SiRFstarII GSP2e/LP	GSP2E/LP-7460	LQFP, 32-bit, 144 pin

ADDITIONAL SOFTWARE OPTIONS

SiRFXtrac (High Sensitivity stand alone software)
SiRFLoc (High Sensitivity multimode software)

For more information, contact your SiRF representative, call our sales force on +1 (408) 467-0410, or visit us at www.sirf.com.

Mobile Compute



Consumer and marine

Automobile



Wireless



SiRF's technology is protected by U.S. and foreign patents pending and issued. SiRF and the SiRF logo are registered trademarks of SiRF Technology, Inc. SiRFstar, SiRF Powered, SnapLock, Foliage Lock, TricklePower, SingleSat, SiRFLoc, SiRFDriVe, SnapStart, Push-to-Fix, SiRF Nav, and SiRFXtrac are trademarks of SiRF Technology, Inc. Other trademarks are property of respective companies.

APPENDIX E

Trip File Data Elements

File Format		Comma Separated Values (CSV) file	
GPS trip records column definition:			
Column Definition	Type	Possible Values	Comment
State (state)	Integer	2 or 3	2: no GPS signal acquired 3: GPS signal acquired
Validity Type (validity)	Integer	127 or 0	127: if the signal is invalid, corresponding to state value 2 0: if the signal is valid, corresponding to state value 3
Solution Type (solution)	Integer	0 or 16	0: corresponding to state value 2 16: corresponding to state value 3
Date (date)	Integer	yyyymmdd	GMT date
Time (time)	Integer	hhmmss	GMT time
Speed (speed)	Real	#.##	Speed in miles per hour
Number of Satellites Available (sat)	Integer	Any integer between 0 to 12	Value ranges from 0 to 12. GPS needs at least 4 satellites to determine a three dimensional position.
PDOP (pdop)	Real	#.##	Positional Dilution of Precision (PDOP) is used to express how favorable the geometry is. Normally, PDOP less than 4 is excellent, between 4 and 5 is very good, between 5 and 6 is good, between 6 and 8 is fair, larger than 8 is poor.
Sensor1 (sensor1)	Integer	1 or 2	On-off status of sensor 1 – not used in this deployment
Sensor2 (sensor2)	Integer	1 or 2	On-off status of sensor 2 – not used in this deployment
Sensor3 (sensor3)	Integer	1 or 2	On-off status of sensor 3 – not used in this deployment
Sensor4 (sensor4)	Integer	1 or 2	On-off status of sensor 4 – not used in this deployment
Sensor5 (sensor5)	Integer	1 or 2	On-off status of sensor 5 – not used in this deployment
RPM (RPM)	Integer		0 r/min to 16383.75 r/min
Pass Counter (PC1)	Integer	0 and 1	Change between 0 and 1
Manifold Air Flow (MAF)	Integer		0 gm/s to 655.35 gm/s (or lb/min)
Pass Counter (PC2)	Integer	0 and 1	Change between 0 and 1

Engine Load Value (load)	Integer		0 (0%) to 255 (100%)
Pass Counter (PC3)	Integer	0 and 1	Change between 0 and 1
Engine Coolant Temperature (CTemp)	Integer		-40 C to 215 C (or in degrees F)
Pass Counter (PC4)	Integer	0 and 1	Change between 0 and 1
Manifold Absolute Pressure (MAP)	Integer		0 kPaA(0%) to 255 kPaA(100%) (or inHg)
Pass Counter (PC5)	Integer	0 and 1	Change between 0 and 1
Vehicle Speed (OBDSpeed)	Integer		kph or mph
Pass Counter (PC6)	Integer	0 and 1	Change between 0 and 1
Throttle Position Sensor (TPS)	Integer		0 (0%) to 255 (100%)
Pass Counter (PC7)	Integer	0 and 1	Change between 0 and 1
Intake Air Temperature (IAT)	Integer		-40 C to 215 C (or in degrees F)
Pass Counter (PC8)	integer	0 and 1	Change between 0 and 1
Ignition Advance (ignition)	Integer		(-64 deg to +63.5 deg)
Pass Counter (PC9)	Integer	0 and 1	Change between 0 and 1
Oxygen Sensor (oxygen)	Integer		bank 1, Sensor 1
Pass Counter (PC10)	Integer	0 and 1	Change between 0 and 1
Quality (quality)	String	Valid, Invalid	Valid: records with state type 3 Invalid: records with state type 2
GPSDIS (gpsdis)	Real	###	Distance in feet between continuous GPS points
Speed Limit (speed_limi)	Integer	5-70	Actual Standard Posted Speed Limit (mph) from Georgia Department of Transportation Roadway Characteristics file

Inventory Year (inv_year)	Integer	00-99	Last two digits of the year of the Roadway Characteristics Inventory for reported roadway section
Access Control (Acess_con)	Character	U, P, F	Control of traffic access to a route U = Free access to the road at grade P = Access at grade are intersecting roads F = Access is gained only at interchanges or rest areas
Operations (operations)	Integer	0 to 7	Direction of traffic flow along route 0 = Can never be used 1 = One-way (non-restricted) 2 = Two-way (non-restricted) 3 = Reversible 4 = One-way during school hours 5 = One-way (with truck restrictions) 6 = Two-way (with truck restrictions) 7 = Through trucks restricted
Travel Lanes (travel_lan)	Character	1-9, 1-9	1 character numeric left, and 1 character numeric right. Represent the number of lanes along the path of a route. Combinations of 1-9 on both character positions representing the actual number of lanes.
Median Divided (median_div)	Character		Describes width and type of median and barrier. First 2 characters code barrier and median combined width in feet, Third character codes median type as follows: 0 = Undivided Road 1 = Grass 2 = Soil, stone 3 = Park, Business 4 = Couplet (2 parallel solid painted lines 4, 8, or 10 ft wide center area) 5 = Concrete 6 = Other 7 = Roadway separated by barrier only (use 4' median width) Fourth Character codes barrier type as follows: 0 = No barrier 1 = Curb 2 = Guardrail 3 = Curb and guardrail 4 = Fence 5 = New Jersey Concrete Barrier 6 = Cable 7 = Other

Functional Class (func_class)	Integer	1-19	Code for functional classification <i>Rural</i> 1 = Interstate Principal Arterial 2 = Principal Arterial 6 = Minor Arterial 7 = Major Collector 8 = NFA Minor collector 9 = Local <i>Urban</i> 11 = Interstate principal arterial 12 = urban freeway and expressway 14 = Urban principal arterial 16 = Minor arterial street 17 = Collector 19 = Local
Heading Change (dheading)	Real	-360 to +360	Heading of previous GPS records minus heading of current GPS record Note: When speed is less than 5 mph, the heading information is not accurate. Hence, heading change is also not accurate.
Turning Indicator (turn)	Integer	0, 1, 2	0: no turning movement identified 1: left turn 2: right turn Note: Currently, a turning movement is identified when speed is larger than 5 mph, and absolute value of heading change is larger than 60 degrees within 10 seconds duration.

APPENDIX F

Participant Survey and Cover Letter

November 4, 2004

Dear -----,

We have nearly completed one year of data collection for the COMMUTE Atlanta Program. The researchers at the Georgia Institute of Technology, as well as our sponsors at The Federal Highway Administration and the Georgia Department of Transportation, would like to thank you for your participation in the Program. You and your family, along with 275 additional households in and around Atlanta, have provided much needed data on the travel patterns and driving characteristics of Atlanta drivers.

As of the end of August, we have collected information on over 750,000 trips made by 500 Atlanta drivers. As a group, you travel around 2 million seconds per day and 350,000 miles per month. We have successfully used the data to identify areas of extreme congestion, and determine general travel characteristics of Atlanta drivers (i.e., miles driven, trips per day per household, and amount of time spent driving).

To make sure that we are using the most accurate information for your household, we would like to ask that you review and complete the following questionnaire. The first three pages will verify information about the household members, vehicles, and drivers of each vehicle. In order to accurately model travel patterns we need to make sure that we have associated the correct person with each household vehicle. Also, if you have sold a vehicle and have forgotten to alert us, this will allow us to begin the process of tracking down those missing units (we retrieved one from Tennessee earlier this year).

The survey also includes one page for each household member of driving age. We would like to ask that each household member review his or her information and complete the section on their driver history. Please note, that this information, like all other information, is held confidential and will only be used for research.

After you complete the survey, please return it to us as soon as possible. We have included a self-addressed, stamped envelope for your convenience. Additionally, you will find included a refrigerator magnet with our contact information in case you have any questions or need to contact us.

Our project sponsors informed us this week that they are very pleased with the results of the present program and have provided an option to extend the research for an additional year. The newly approved research program will actually provide financial incentives to households that continue to participate. We will contact you within the next couple of months to see if your household is interested in continuing participation for the extended period. As always, your participation is voluntary.

We appreciate you taking the time to help with this very important survey. If you have any questions or concerns about the study, please feel free to contact us at the COMMUTE Atlanta Hotline 404-385-2376.

Sincerely,

Jennifer Harper Ogle
Research Engineer

General Household Information

Household Contact Information

Please check the accuracy of the contact information and mark any changes below in pen.

Last Name [REDACTED]
First Name [REDACTED]
Address [REDACTED] Way
City Jonesboro
State GA
Zip Code 30236
Home Phone [REDACTED]
Work Phone [REDACTED]
Cell Phone [REDACTED]
Email [REDACTED]

Household Member Information

Person	First Name	Relationship to Contact	Gender	Age
1	[REDACTED]	Self	Female	38
2	[REDACTED]	Spouse / Partner	Male	42
3	[REDACTED]	Son / Daughter	Female	6
4	[REDACTED]	Son / Daughter	Male	4
5	[REDACTED]	Son / Daughter	Male	1

Number of people currently in your household 5

If any household members are not listed above, please provide their information in the space below. Please be sure to provide name, relation to contact, gender, and age for all other members.

Person	First Name	Relationship to Contact	Gender	Age
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

General Household Information

Household Vehicle Information

We instrumented some or all of the vehicles in your household, but need to make sure we have correct information on all of your current vehicles.

Please check the accuracy of the vehicle information and make any changes below.

<i>Vehicle #</i>	<i>Year</i>	<i>Make</i>	<i>Model</i>	<i>Equipment Installed?</i>	
1	1996	Nissan	Quest	Yes	No
2	1998	Lincoln	Town Car	Yes	No

Number of vehicles currently owned/leased by your household

2

Please cross out any vehicles in the list above that are no longer in your household.
Please add any new vehicles in the spaces below.

<i>Vehicle #</i>	<i>Year</i>	<i>Make</i>	<i>Model</i>	<i>Odometer Reading</i>	<i>Reading Date</i>
_____	_____	_____	_____	_____ miles	_____
_____	_____	_____	_____	_____ miles	_____
_____	_____	_____	_____	_____ miles	_____

General Household Information

Driver Information

For each vehicle, please provide primary and secondary drivers and percentage of time spent driving each vehicle. Total for each vehicle should be 100%.

EXAMPLE: 1999 Dodge Caravan

<i>Driver Names</i>	<i>% Time Driving</i>
---------------------	-----------------------

<i>Jane Doe</i>	<i>75%</i>
-----------------	------------

<i>John Doe</i>	<i>25%</i>
-----------------	------------

Vehicle 1: _____

<i>Driver Name</i>	<i>% Time Driving</i>
--------------------	-----------------------

_____	_____
-------	-------

_____	_____
-------	-------

_____	_____
-------	-------

Vehicle 2: _____

<i>Driver Name</i>	<i>% Time Driving</i>
--------------------	-----------------------

_____	_____
-------	-------

_____	_____
-------	-------

_____	_____
-------	-------

Vehicle 3: _____

<i>Driver Name</i>	<i>% Time Driving</i>
--------------------	-----------------------

_____	_____
-------	-------

_____	_____
-------	-------

_____	_____
-------	-------

Vehicle 4: _____

<i>Driver Name</i>	<i>% Time Driving</i>
--------------------	-----------------------

_____	_____
-------	-------

_____	_____
-------	-------

_____	_____
-------	-------

Vehicle 5: _____

<i>Driver Name</i>	<i>% Time Driving</i>
--------------------	-----------------------

_____	_____
-------	-------

_____	_____
-------	-------

_____	_____
-------	-------

Others:

Household Member Information

Household Contact :

Household Member: [REDACTED]

Please check the accuracy of the personal information and make any changes below.

Last Name [REDACTED]
First Name [REDACTED]
Relationship to Contact Spouse / Partner
Gender Male
Age 42
Work Situation Work Full Time
Employer Name [REDACTED]
Employer Address 1
Employer Address 2
Occupation Sales or Service
Student Status No
Current School Level
School Name
Highest Education Level Bachelors

Please answer the following questions regarding your driving history.

This information will be kept completely confidential and used only for research.

How long have you had a drivers license? _____ year(s)

How many speeding tickets have you received in the last 5 years? _____
...in your lifetime? _____

How many crashes have you been involved in as a driver in the last 5 years? _____
...in your lifetime? _____

If you were involved in one or more crashes within your lifetime,
how many crashes were you found to be at fault for? _____
how many crashes involved injuries? _____

On a regular basis, do you drive faster than the posted speed limit? (circle one) Yes No

In general, how do you feel about posted speed limits? (check one)

☐ speed limits too low ☐ speed limits adequate ☐ speed limits too high

The last time you drove a vehicle, did you wear your seat belt? (circle one) Yes No

Friday, June 11, 2004

Household Member Information

Household Contact :

Household Member: [REDACTED]

Please check the accuracy of the personal information and make any changes below.

Last Name [REDACTED]
First Name [REDACTED]
Relationship to Contact Self
Gender Female
Age 38
Work Situation Work Full Time
Employer Name [REDACTED]
Employer Address 1 [REDACTED]
Employer Address 2 [REDACTED]
Occupation Professional, managerial, or technical
Student Status No
Current School Level [REDACTED]
School Name [REDACTED]
Highest Education Level Graduate

*Please answer the following questions regarding your driving history.
This information will be kept completely confidential and used only for research.*

How long have you had a drivers license? _____ year(s)

How many speeding tickets have you received in the last 5 years? _____
...in your lifetime? _____

How many crashes have you been involved in as a driver in the last 5 years? _____
...in your lifetime? _____

If you were involved in one or more crashes within your lifetime,
how many crashes were you found to be at fault for? _____
how many crashes involved injuries? _____

On a regular basis, do you drive faster than the posted speed limit? (circle one) Yes No

In general, how do you feel about posted speed limits? (check one)

☐ speed limits too low ☐ speed limits adequate ☐ speed limits too high

The last time you drove a vehicle, did you wear your seat belt? (circle one) Yes No

Friday, June 11, 2004

APPENDIX G

Model Variables

DRIVER MODEL	TRIP MODEL	TYPE	VARIABLES	DESCRIPTION
DEPENDENT VARIABLES				
X			Number of trips where PSL exceeded/Total Number of Trips	This variable spans the two-week duration.
X			Number of trips where PSL+XX mph exceeded/Total Number of Trips	This variable spans the two-week duration.
	X		Exceeded PSL	0 - not exceeded; 1 - exceeded
	X		Exceeded PSL+XX mph	1 - not exceeded; 1 - exceeded
INDEPENDENT VARIABLES				
SOCIO-DEMOGRAPHIC VARIABLES				
X	X	nominal	Gender	Value Label 0 Male 1 Female
X	X	Scale	Age	
X	X	ordinal	Age Group	Value Label 1 15-24 2 25-34 3 35-44 4 45-54 5 55-64 6 65+
x	X	nominal	Employment Status	Value Label 1 Work Full Time 2 Work Part Time 3 Homemaker 4 Retired 5 Disabled 6 Unemployed/Looking 7 Unemployed/Not Looking 8 Don't Know 9 Refused
X	X	nominal	Occupation	Value Label 1 Sales or Service 2 Clerical or Admin Support 3 Mfg, Constr, Maint, Farm 4 Professional 5 Military 97 Other, Specify 98 Don't Know 99 Refused
X	X	nominal	Student Status	Value Label 1 Yes 2 No 98 Don't Know 99 Refused
X	X	nominal	Educational Attainment	Value Label 1 Less than High School 2 High School Graduate 3 Some College 4 Vocational/Technical 5 Bachelors 6 Graduate 8 Don't Know 9 Refused
X	X	nominal	County	Value Label 13057 Cherokee 13063 Clayton 13067 Cobb 13077 Coweta 13089 Dekalb 13097 Douglas 13113 Fayette 13117 Forsyth 13121 Fulton

				13135 Gwinnett 13151 Henry 13223 Paulding 13247 Rockdale 99999 Unknown
X	X	scale	Total Number of Household Vehicles	Could be nominal
X	X	scale	Total Number of Household Members	
X	X	nominal	Ethnicity	Value Label 1 Black/African American 2 Latino/Hispanic/Spanish 3 Asian/Pacific Islander 4 Native American 5 White Caucasian 7 Other 8 Don't Know 9 Refused
X	X	ordinal	Total Household Income	Value Label 11 < \$10,000 12 \$10,000 - \$19,999 13 \$20,000 - \$29,999 14 \$30,000 - \$39,999 15 \$40,000 - \$49,999 16 \$50,000 - \$59,999 17 \$60,000 - \$74,999 18 \$75,000 - \$99,999 19 \$100,000 +
X	X	ordinal	Net Residential Density Level (Dwelling Units per Acre)	Value Label 1 0 to < 2 2 2 to < 4 3 4 to < 6 4 6 to < 8 5 8 +
X	X	nominal	Married or Single	Value Label 0 Single 1 Married/Partner
X	X	scale	Number of Dependent Children under Age 13	
X	X	scale	Number of Dependent Children over Age 13	
X	X	nominal	Dependent Children?	Value Label 0 No 1 Yes
DRIVER PERFORMANCE VARIABLES				
X	X	nominal	Unique Box ID	Indicates an individual person/vehicle combination
X	X	scale	Number of Citations Received in Crashes 2000-2003	
X	X	scale	Number of Crashes At Fault 2000-2003	
X	X	scale	Number of Crashes Not At Fault 2000-2003	
X	X	scale	Total Number of Crashes from 2000 - 2003	
X	X	scale	Total Exposure March 8-23 (miles)	
VEHICLE VARIABLES				
X	X	scale	Vehicle Age	
X	X	scale	Odometer Reading	
X	X	nominal	Vehicle Body Type	Value Label 1 Auto 2 Van 3 SUV 4 Pickup 5 Other Truck 6 RV (NA) 7 Motorcycle (NA) 97 Other 98 Don't Know 99 Refused
TRIP VARIABLES				
	X	nominal	Unique Trip ID	

	X	scale	Trip Start Hour (0-23)	
	X	scale	Trip Duration (minutes)	
	X	scale	Trip Distance (miles)	
	X	scale	Average Trip Speed (mph)	
	X	nominal	Rural or Urban	
	X	nominal	Peak or Off-Peak	Value Label 0 Off-Peak (10 AM - 3 PM, 7 PM - 6 AM) 1 Peak (6 AM - 10 AM, and 3 PM - 7 PM)
	X	nominal	AM Peak or PM Peak	Value Label '0' AM Peak '1' PM Peak
	X	scale	Percent of Observations on Interstate	
	X	scale	Percent of Observations on Fwy Expwy	
	X	scale	Percent of Observations on Principal Arterial	
	X	scale	Percent of Observations on Minor Arterial	
	X	scale	Percent of Observations on Collector	
	X	scale	Percent of Observations on Local	
	X	Ordinal	Day of Week	Value Label 1 Monday 2 Tuesday 3 Wednesday 4 Thursday 5 Friday 6 Saturday 7 Sunday
	X	Nominal	Weekday or Weekend	Value Label 1 Weekday 2 Weekend
	X	Nominal	Lighting Condition	Value Label 1 Dawn 2 Daylight 3 Dusk 4 Dark

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